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AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD CONFERENCE PROCEEDINGS 602

Strategic Management of the Cost Problem of Future Weapon Systems

(Gestion stratégique des coûts des futurs systèmes d'armes)

Papers presented at the Flight Vehicle Integration Panel Symposium held in Drammen, Norway, 22-25 September 1997.

NORTH ATLANTIC TREATY ORGANIZATION

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According to its Charter, the mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

— Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community;

— Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development (with particular regard to its military application);

— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

— Improving the co-operation among member nations in aerospace research and development;

— Exchange of scientific and technical information;

— Providing assistance to member nations for the purpose of increasing their scientific and technical potential;

— Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field.

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* AGARD merged with the Defence Research Group of NATO (DRG) on 1 January 1998 to form the Research and Technology Organization (RTO) of NATO. However, both AGARD and DRG will continue to issue publications under their own names in respect of work performed in 1997.

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Strategic Management of the Cost Problem of Future Weapon Systems

(AGARD CP-602)

Executive Summary

This publication contains the papers that were presented at the AGARD/RTO Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems". It was held on 22-25 September 1997 in Drammen, Norway. This event was prepared and organized under the auspices of the former AGARD Flight Vehicle Integration Panel (FVP).

The selection of the topic and the further definition of the desired contents of the Symposium was based, in the usual manner, on suggestions and proposals by Panel Members. The first suggestions for a Pilot Paper were made by Dr. Filisetti (I) in 1992. Subsequently, Professor L. da Costa Campos (P) was made a co-author, to be joined by Mr E. Lojacono (I) and Mr. L.M. Nicolai (US) in 1993. The final version of the Pilot Paper, defining the topics to be covered, was prepared by Leland M. Nicolai in 1995 and it served as a template for the Symposium.

The rationale for the importance and the timeliness of its subject was stated succinctly in the Announcement of the Symposium:

> Today, and well into the future, all NATO members face the challenge of maintaining combat effective air forces within the constraints of ever-shrinking defence budgets. Successful strategic management of the cost problems of future weapon systems will be crucial to meeting this challenge. This symposium aims to present lessons learned from recently completed as well as on-going programs. It will present methods for low-cost manufacturing, and present the government perspective on the need to establish realistic cost targets and then manage the programme to meet those targets. Thus, the goal of this symposium will be to share best practices based on the experiences of the government, the military customer, and the industry providers; in so doing, it is hoped to provide a reference and stimulation for new ideas to help the Nations meet the cost challenge of the 21st century.

In the opinion of the Co-Chairmen of the Symposium, the intended topics were well covered by the spectrum of authors and their individual presentations. With the vital assistance of the National Points of Contacts, there was also a good representation of various NATO nations, so building a useful, enriched common experience. We enjoyed hearing the papers and meeting the authors. We consider the material now published in this report to be of excellent calibre and effective in attaining the aims of the Symposium. We trust that the readers will concur.

La gestion stratégique du problème du coût des futurs systèmes d'armes

(AGARD CP-602)

Synthèse

Cette publication contient les communications présentées lors du symposium AGARD/RTO sur "La gestion stratégique du problème du coût des futurs systèmes d'armes", qui a été organisé à Drammen en Norvège, du 22 au 25 septembre 1997. Cette conférence a été conçue et organisée sous l'égide de l'ancien Panel AGARD de conception intégrée des véhicules aérospatiaux (FVP).

Comme c'est la coutume, le choix du thème et la définition du programme ont été guidés par des suggestions et des propositions faites par les membres du Panel. Les premières propositions, concernant une présentation pilote, ont été faites par le

L'actualité et l'importance du sujet sont précisées de façon succincte dans l'annonce de la réunion :

> Aujourd'hui, l'ensemble des pays membres de l'OTAN doit relever le défi qui consiste à maintenir des forces aériennes disponibles pour le combat malgré les contraintes imposées par des budgets de défense en diminution constante. La gestion stratégique convenable des problèmes de coût des futurs systèmes d'armes sera capital pour le relèvement de ce défi. Ce symposium présente les enseignements tirés de différents programmes récents et en cours. Des méthodes de fabrication à faible coût seront présentées, ainsi que la perspective gouvernementale en ce qui concerne l'établissement d'objectifs de coûts réalistes et la gestion des programmes permettant de les atteindre. Ainsi, ce symposium a pour but de mettre en commun les meilleures pratiques, sur la base de l'expérience gouvernementale, militaire et industrielle, afin de fournir aux nations une référence et de nouvelles idées leur permettant de relever le défi des coûts du 21ème siècle.

De l'avis des co-présidents du symposium, les sujets annoncés ont été traités de façon très complète par les différents auteurs. L'aide précieuse apportée par les Points de contact nationaux a garanti une bonne représentation des pays membres de l'OTAN, enrichissant ainsi les échanges fructueux qui ont pu se faire entre les participants. Nous avons apprécié les présentations ainsi que les contacts que nous avons pu avoir avec leurs auteurs.

Nous considérons que les textes qui figurent dans ce rapport, qui sont de très grande qualité, ont largement contribué à la réalisation des objectifs du symposium et nous espérons que nos lecteurs seront du même avis.

Contents

† Paper not available for publication.

† Paper not available for publication.

Theme

Today, and well into the future, all NATO members face the challenge of maintaining combat effective air forces within the constraints of ever-shrinking defence budgets. Successful strategic management of the cost problem of future weapons systems will be crucial to meeting this challenge. This symposium aims to present lessons learned from recently completed as well as on-going programs. It will present methods for low-cost manufacturing, and present the government perspective on the need to establish realistic cost targets and then manage the program to meet those targets. Thus, the goal of this symposium will be to share best practices based on the experiences of the government, the military customer, and the industry providers; in so doing, it is hoped to provide a reference and stimulation for new ideas to help the Nations meet the cost challenge for the 21st century.

Thème

Aujourd'hui et dans un avenir prévisible, les pays membres de l'OTAN doivent relever le défi qui consiste à maintenir des forces aériennes efficaces au combat tout en respectant les contraintes imposées par les budgets de défense en continuelle diminution. La réussite de la gestion stratégique des coûts des futurs systèmes d'armes est l'élément clé du relèvement de ce défi. Ce symposium a pour objectif de présenter les enseignements tirés des programmes en cours et déjà réalisés. Il examinera les méthodes de la fabrication à coût modéré, et présentera la perspective gouvernementale concernant la nécessité d'établir des objectifs de coûts réalistes et de gérer ensuite des programmes conçus pour les atteindre. Ainsi, le but de ce symposium est de permettre la mise en commun des meilleures pratiques dans ce domaine, basées sur l'expérience de l'administration, des clients militaires et des fournisseurs industriels. En agissant ainsi, les organisateurs comptent fournir, d'une part une référence, et d'autre part un encouragement aux idées nouvelles, en vue d'aider les pays membres à relever le défi des coûts au 21ème siècle.

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KEYNOTE ADDRESS ON:
"ISSUES AFFECTING PROCUREMENT OPTIONS"

BY

MAJOR GENERAL IVAR GJETNES
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Mr. Chairman

It is with great pleasure that I have accepted the invitation to address this symposium of experts in the fields of cost management. Strategic management of cost related issues is indeed a very important area of concern to all those who are involved in procurement of technically advanced weapon systems. Some would add that it is a particularly relevant problem in this time and age of dwindling defense budgets. On the other hand, it is easy to argue that the question of cost and affordability has always, and will always, be with us no matter how large or small the funds for procurement of military hardware may be.

It is exciting for me to share with you some personal thoughts on issues concerning cost, that affect procurement of weapon systems in the future. Although I am grateful for this opportunity to address the symposium, I am also grateful that my mission here to-day is NOT to provide the answers. Rather, my task is to put into focus issues that I think are - or will become - relevant for all those working within our profession, and especially so for those who are struggling to help people like me cope with the economic situation which will have to be faced in the years ahead.

PERSPECTIVE

Obviously, as a representative of a small country within the NATO alliance, my views will primarily be from the perspective of a small procurement agency. However, as we all move in a direction of reduced acquisition budgets, the issues that I touch on may soon become significant to most!

As an introduction to the specific issues that I want to present, it seems appropriate to make a few observations on how evolutionary trends of industrial corporations have

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

affected cost management. Years ago, industry attempted to reduce costs by limiting risk through a process of diversification. It was the established truth that companies with very narrow technological expertise were especially vulnerable to changes in demand. In order to remain competitive it was assumed that it was necessary to expand through alliances with companies in other fields of expertise which could broaden the production spectrum.

It soon became evident that some of the vulnerable branches of the expanded corporations were less profitable than others. Thus, instead of maintaining the broad production spectrum which was introduced to reduce risk and cost, it now became fashionable to divest the less profitable elements as part of a new trend, namely to maintain the core business. Returning to the core business has in many ways reestablished the situation before diversification.

Since then, we have experienced yet another attempt at increasing the profit margin, this time through consolidation, whereby corporations within the same area of expertise join forces. The official rationale is that this will assure a sufficient production base for the future. It is also certain to remove troublesome competition!

Perhaps the next trend for industry will be to split design and production into different independent corporations, or to revert back to smaller manufacturing companies, that will be able to adjust more easily to changing customer demands.

As any procurement agency looks into the future, it may be necessary to assess the impact on procurement of whatever economic theory or business strategy comes next. In any case, it is interesting to note that during all these changes, military procurements have experienced increased costs well beyond normal inflation, assumed to be costs due to technological innovation, while at the same time introduction of new technology has dramatically reduced costs for consumer goods.

AIM

Coping with the topic of this symposium, "Strategic management of the cost problem of future weapon systems", involves a series of issues facing government agencies and industry alike, which affect procurement activities, research and development, organization of military forces, political alliances and the general world wide security situation.

The aim of my address is to suggest that there are several options available to handle the cost problem. Some of these options do not follow the prevailing thoughts. For instance, the future may well show that there are opportunities for both large and small manufacturers, research facilities and other corporate entities, depending on how emerging challenges are being met. The solution to the cost problem may lie as much in enhanced cooperation and joint exploitation of available resources as with consolidation and mergers into "mega" corporations. If we are to maintain a comfortable level of common security at low cost, I am convinced that the optimal way to manage the cost problem lies in a gradual relinquishing of the traditional national "sovereignty".

ISSUES

I have elected to focus on the following 4 issues that in my opinion will affect our future procurement options, and which could have substantial cost impacts on the acquisition of major weapon systems:

-Specialization of military tasks within the framework of combined, joint operations

-Industrial and military procurement cooperation

-Industrial off-set

-Cooperation in research, development and production.

Specialization of military tasks

The several instances of UN authorized international military operations involving multinational forces, indicate that the world community in the future may be more aggressively involved in trouble shooting around the world. We have seen that a successful completion of such missions involves not only unified command and control, for instance through the use of the established structure of the NATO alliance, but equally important by the careful integration of forces with dissimilar capabilities.

It seems that the time has come to recognize that perhaps no nation within the alliance can assemble forces that are sufficiently balanced to be able to cope effectively with the majority of potential conflicts that will have to be dealt with in the future, even including their own national defense. Hence, one solution to the cost problem is to establish agreements which give participating countries the option to concentrate resources on the development of forces with special but limited capabilities. The intent should be that these forces at the same time provide a necessary contribution to the establishment of any required combined joint force. Through specialization of tasks and forces, each nation may in this way concentrate its limited resources to meet only selected elements of what used to be a much larger national military obligation. Based on this option, it will only be necessary to expend funds to develop and procure weapon systems that are peculiar to the special tasks which have been assigned to the forces of participating countries.

It is my opinion that specialization of tasks and forces will limit the number of weapon systems that each nation has to procure and maintain, and that this option will significantly reduce life cycle costs.

Industrial and military procurement cooperation

Within the aerospace industry we are now watching "mega" companies developing, companies that appear to make the old Soviet style monopolies look like local work shops in comparison. It is interesting that these new corporations are being approved by governments that previously have been so keen to fight against structures that tend to reduce the advantages of competition. From the perspective of any procurement agency, it is important to analyze the effects of synergy through consolidation against the effects of reduced competition.

As an example, the European aerospace industry has consolidated within national boundaries. This consolidation has made it very difficult to establish pan-European companies, which could have provided a more competitive environment. Today, the only likely trend away from the present, seems to be an evolution towards only one large aerospace company in Europe, which would clearly limit competition. Perhaps the time has come to closely evaluate other possible alternatives, even those involving future cooperation or integration with aerospace companies within the Former Soviet Union.

On the other hand, if the consolidation of the European aerospace industry would result in an entity strong enough to compete effectively with the remaining aerospace giants of the United States, we may eventually see a true "two-way street" situation develop across the Atlantic, a situation which could assure competition and reasonable costs of future weapon systems. Another possible trend may be trans-Atlantic corporate partnerships that would offer other non-competitive advantages.

In order to take advantage of industrial consolidation, it is necessary that military procurement organizations develop closer cooperation. As a result we may be able to exploit common requirements and the need for interoperability to abolish or significantly limit peculiar national options. This may in turn pave the way for truly common procurement organizations. Some such agencies have already seen the light of day, exemplified by the Joint Strike Fighter System Program Office, and the NATO Eurofighter Tornado Management Agency.

Military procurement agencies, such as materiel commands, still remain national institutions, and it is difficult for political reasons to transfer decision-making in acquisition management to multinational agencies. However, it is interesting to note that the political climate is changing, as indicated by the proposed establishment of a common procurement agency between some of the larger European NATO member states.

In my opinion, the present trend towards industrial consolidation can only be properly exploited through closer military cooperation on procurement of future weapon systems, including the establishment of common procurement agencies. Acting on behalf of several countries, such common agencies could provide consolidated business approaches and technological solutions which would assure interoperability and lower life cycle cost.

Industrial off-set

For a small country, with an extremely limited production capability for major weapon systems, the cost issue rapidly becomes a function of industrial off-set. Procurements of major weapon systems represent substantial investments, for many countries occasionally totaling an entire annual defense budget. It is obvious, therefore, that such large purchases from suppliers in another country will generate a need for reciprocity. In return for purchases, governments have been directing foreign contractors to procure specific types of materiel or services.

The World Trade Organization and similar international bodies have considered changes to the present rules and regulations, which exempt military equipment from the general rules of trade. Even if such changes are introduced, it seems to me that in a competitive environment governments will still in practice be able to insist on acceptable industrial off-set for major procurements.

Satisfying the requirements of industrial off-set becomes a practical problem when the total value of procurement of major weapons systems is large compared to the off-set

possibilities in smaller countries. A foreign contractor may find it difficult to generate economically sound off-set contracts because of incompatible technology, national policy and limited production capacity. In any case, it will be a challenge to establish off-set contracts that in economic terms approach the purchase price of major weapon systems. Contractors may solve their problem by buying off-set from other large corporations, as long as these other corporations have commercial interests which are more compatible with the industrial base of the country which is procuring the weapon system.

In my opinion, there is still another option - involving procurement agencies and industry of so-called 3rd countries - to facilitate an off-set agreement. By this I mean that it could be possible to link military procurements of several countries. This scheme may work if the 3rd country has an industrial and technological base which is more compatible with the industry of the country which initially generated the off-set requirement.

As an example, consider a major procurement by Norway of a new combat aircraft. It is difficult to generate off-set contracts for the purchase price within the technological areas of primary interest to major aerospace contractors, because of a very limited aerospace industry in Norway. Potential suppliers of combat aircraft, as well as Norwegian defense agencies and defense related industries may, however, have substantial commercial interests involving military authorities and industry in a 3rd country. In that case, parts of the off-set requirement could be initially satisfied through contracts between the supplier of combat aircraft and industry in the 3rd country. This industry - in turn - could establish contracts with Norwegian defense related industry for production of equipment which is being procured by military authorities of the 3rd country, and which is compatible with the production capability and capacity of Norwegian industry.

Finally, it is an interesting observation that off-set requirements may in fact be needed to assure future competition. If a defense contractor wants to sell high technology equipment to a small country, then reciprocal purchases of advanced equipment of the

same or similar technology are necessary. Contractors that need to provide off-set would, therefore, have a self interest in maintaining the technological level of the industry of countries procuring major weapon systems. This creates a balance which helps assure that there will continue to be a technological basis for an alternate supplier

Cooperation in research, development and production

Maintaining independent research and production capabilities has in the past been considered essential for the security of nation states. Introduction of collective security through world organizations such as the United Nations has not diminished this national objective. However, more closely knit defense alliances, such as NATO, have at least provided a certain impetuous towards development of common equipment and capabilities. Never-the-less, we still maintain substantial defense research and production facilities that operate outside the scope of normal competition.

In strategic terms it seems likely that the integration process in Europe will continue, and that the NATO alliance will be in existence for the foreseeable future. Hence, it becomes ever more important to find ways to integrate national initiatives and capabilities. Europe has over the years been suffering from the effects of maintaining specific national capabilities, that have prevented cost effective cooperation on development and production of technologically advanced systems. It is obvious that tremendous resources have been expended in sum by the European NATO members for development of similar equipment. There must be another way.

What we need in the future - in my opinion - is a change in political will to create a common multinational institution (within NATO, WEAG and/or others), with the responsibility to consolidate the use of technical and scientific expertise in various fields, creating international teams of experts. The purpose should be to reduce duplication of work, and assure that the best minds from all participating countries are

involved in major development programs. One result should be a substantial reduction in program costs.

Similarly, as the number of major defense procurement programs is reduced, it is necessary to assure that the development and production capabilities of the few remaining contractors are maintained for competition on future programs. One way may be to divert a portion of the development and production work to an unsuccessful bidder, or perhaps to design future contracts such that several contractors have to combine resources in order to accomplish the contract task. This could be done by establishing common design and production teams, which at the same time would assure a level of technology transfer between companies.

In the future, major procurement programs will be fewer and far between. They will also most likely involve lower quantities of equipment. Based upon this assumption it is necessary to modify production processes. Mass production, especially of major weapon systems, will most likely be replaced by reduced capacity methods. Different techniques will have to be developed to accommodate this in an effective manner. So-called "lean" initiatives, such as the Lean Aircraft Initiative (LAI), seem like good methods of improving work processes. Some initiatives, however, seem to represent good, established practices that are being reintroduced and presented in new "packaging", rather than being new knowledge, or new revolutionary ways of doing business. In any case, it is important continuously to assess production efficiency, and to evaluate the applicability of processes that have proved valuable by other industries, or even those that have been discarded in the past.

Clearly, the establishment of peculiar requirements have had, and continue to have, significant impacts on the cost of major weapon systems. We have seen that the use of military standards has tended to limit the design options and increase costs. In my opinion there is nothing wrong with neither peculiar options nor military standards as such. When buying into a family of weapons product it may very well be necessary to modify the basic design to accommodate special operational needs. Cost reductions have already been realized by the family concept. Similarly, military as well as

commercial specifications must evolve with changes in technology and operational needs. And if they do, they are required in order to avoid repeating unnecessary mistakes.

As more and more weapon systems experience lower usage profiles, and more and more time is spent waiting for the next mission, I feel that it is time for a re-evaluation of the current design criteria. In my opinion, design concepts based on "Design-to-cost" may need to be replaced or at least modified by concepts that emphasize what could be called "design-to-minimum-required-life". As an example, an air-to-air missile is designed to last only one flight! Perhaps we could reduce procurement and life cycle cost if military equipment in general was designed to always be ready for the next mission, rather than to outlive by far its useful operational life. To be successful such a design philosophy requires significant changes in the way we train and use military forces, and in how we maintain readiness and sustainability.

CONCLUSION

The aim of my address was to point out a few of the cost related issues that in my personal opinion are major drivers in the management of the cost problem related to procurement of major weapon systems.

Several options are available, and a number of them do not follow the prevailing thoughts. I hope that I have touched on some of those! From an economic point of view, I am convinced that the solutions lie in a gradual relinquishing of the traditional national "sovereignty".

I hope that I have provided some "food for thought" that may be useful during the seminar discussions.

I thank you for your attention.

(IG, 97.09.21)

SKUNK WORKS LESSONS LEARNED

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THE SKUNK WORKS APPROACH

The Lockheed Skunk Works has demonstrated a unique ability to rapidly prototype, develop and produce a wide range of highly advanced aircraft for the U.S. armed forces and intelligence agencies (See Figure 1). The P–80, U–2, F–104, SR–71, F–117, YF–22 and, more recently, the Tier 3– Dark Star are widely recognized as among the most significant achievements of the aerospace industry. These and other Skunk Works aircraft have incorporated breakthrough technology to achieve new thresholds in aircraft and system performance. The common thread among these aircraft is that they were created by men and women working together employing a unique approach to aircraft development — the Skunk Works approach. This management approach, developed by the founder of the Skunk Works – C, L. "Kelly" Johnson, fosters creativity and innovation, and has enabled prototyping and development of highly complex aircraft in relatively short time spans and at relatively low cost. It has also demonstrated efficient, economical production of complex systems in small quantities and at low production rates.

The Skunk Works Operating Rules

Based on lessons learned from early Skunk Works programs, Kelly Johnson developed and wrote the Basic Operating Rules of the Skunk Works. These fourteen "rules" address program management, organization, contractor/customer relationships, documentation, customer reporting, specifications, engineering drawings, funding, cost control, subcontractor inspection, testing, security, and management compensation. Although the language does not sound as if it would be applicable in today's environment, the basic principles are relevant and are applied in present Skunk Works' operations on a regular basis. (Comments in Italics expand the reasons behind the rules.)

1. The Skunk Works' manager must be delegated practically complete control of his program in all aspects. He should report to a division president or higher. *(It is essential that the program manager have authority to make decisions quickly regarding technical, finance, schedule, or operations matters.)*

2. Strong but small project offices must be provided both by the customer and contractor. *(The*

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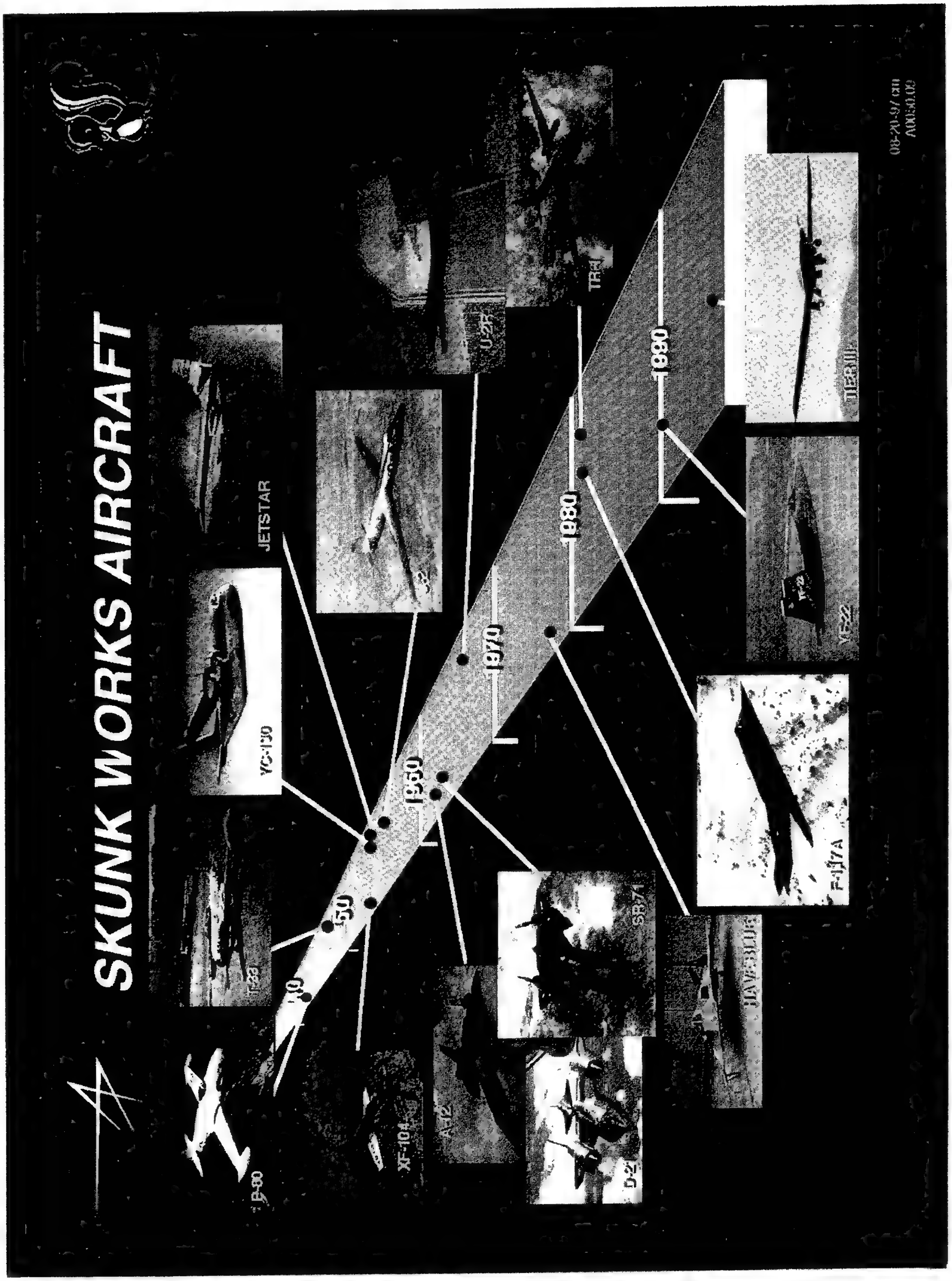

Figure 1. 50 Years of Skunk Works Aircraft

customer program manager must have similar authority to that of the contractor.)

3. The number of people having any connection with the project must be restricted in an almost vicious manner. Use a small number of good people (10 to 25 percent compared to the so–called normal systems). *(Bureaucracy makes unnecessary work and must be controlled brutally.)*

4. A very simple drawing and drawing release system with great flexibility for making changes must be provided. *(This permits early work by manufacturing organizations, and schedule recovery if technical risks involve failures.)*

5, There must be a minimum of reports required, but important work must be recorded thoroughly. *(Responsible management does not require massive technical and information systems.)*

6. There must be a monthly cost review covering not only what has been spent and committed, but also projected costs to the conclusion of the program. Don't have the books ninety days late and don't surprise the customer with sudden overruns. *(Responsible management does require operation within the resources available.)*

7. The contractor must be delegated and must assume more than normal responsibility to get good vendor bids for the subcontract on the project. Commercial bid procedures are very often better than Mil Spec ones. *(Essential freedom to use the best talent available and operate within the resources available.)*

8. The inspection system as currently used by the Skunk Works, which has been approved by both the Air Force and Navy, meets the intent of existing military requirements and should be used on new projects. Push more basic inspection responsibility back to subcontractors and vendors. Don't duplicate so much inspection. *(Even the commercial world recognizes that quality is in design and responsible operations not inspection.)*

9. The contractor must be delegated the authority to test his final product in flight. He can and must test it in the initial stages. If he he isn't, he rapidly loses his competency to design other vehicles. *(Critical, if new technology and the attendant risks are to be rationally accommodated.)*

10. The specification applying to the hardware must be agreed to in advance of contracting. The Skunk Works practice of having a specification section stating clearly which important military specification items; will not knowingly be complied with and reasons therefore is highly recommended. *(Standard specifications inhibit new technology and innovation, and are frequently obsolete.)*

11. Funding a program must be timely so that the contractor doesn't have to keep running to the bank to support government projects. *(Respnsible management requires knowledge of and freedom to use, the resources originally committed.)*

12. There must be mutual trust between the customer project organization and the contractor with very close cooperation and liaison on a day–to–day basis. This cuts down misunderstanding and correspondence to an absolute minimum. *(The goals of the customer and producer should be the*

same – get the job done well.)

13. Access by outsiders to the project and its personnel must be strictly controlled by appropriate security measures. *(This is a program manager's responsibility even if no program security demands are made – a cost avoidance measure.)*

14. Because only a few people will be used in engineering and most other areas, ways must be provided to reward good performance by pay not based on the number of personnel supervised. *(Responsible management and technical/operational personnel must be rewarded. Responsible management does not permit the growth of bureaucracies.)*

Since its inception in 1943, the Skunk Works has completed a significant number of projects that have resulted in development and/or production hardware. These programs vary significantly in terms of type of product, technologies, customer, contracts, specifications, support requirements, and other parameters. However, there are some general characteristics that emerge:

- Need to rapidly field a new capability
- Requirement for new technology breakthroughs
- Willingness to accept risk – contractor and customer
- Use of prototyping to reduce development risk
- Low rate and low quantity production
- Specialized management methods required and accepted
- Need and/or desire to maintain tight security

The Have Blue stealth technology demonstrator and F–117 stealth fighter are two recent highly successful Skunk Works programs that have these general characteristics.

More than ever, the current environment demands that each acquisition dollar be spent wisely and efficiently. The Skunk Works management approach offers a proven, quick, efficient way to: develop new technology through prototyping; execute engineering and manufacturing development (EMD) programs; procure limited production systems at low rates; and upgrade current systems with new technology.

Program Management

A Skunk Works program is organized around a program manager who is given total control of all program aspects including engineering, test, manufacturing, quality assurance, security,.plans and schedules, budget control, etc. Thus, the program manager has the ability to control his costs and meet rational program milestones and objectives.

Other functional organizations within the Skunk Works (Lockheed Advanced Development Company) such as human resources, information services, facilities, environmental health and safety, and legal provide "on demand" support to the program managers. Furthermore, staff support in any specialty area of the corporation is available to the program manager if needed. As a program grows and transitions into development and production, additional functions are added such as product support, training, and assistant program managers for specific program end items as needed,

Skunk Works program offices are small. For example, at the height of F–117 development and production, the Skunk Works management team was 20 to 30 people total, and the Air Force's System Program Office (SPO) was similar in size. The objective is to establish a "one–on–one" relationship between the Skunk Works and customer procurement teams, with clear lines of responsibility and full authority for all managers, both contractor and customer,

The Skunk Works approach also demands the use of a small number of high quality individuals staffing each function. Individuals are given broad responsibility and have a substantial workload. Our experience has shown that under these circumstances individual achievement is most often much higher than management's expectations. The F–117 is a program that achieved excellent results while using a relatively small number of people. The maximum number of direct Skunk Works employees during each phase follows :

Have Blue Demonstrator	340
Full–Scale Development	2500
Production............................	4000
Sustaining Support	1200

The benefits of keeping both management and total personnel at a minimum are: greater individual responsibility and satisfaction; better communications; high productivity; and reduced costs .

The key to success is a cohesive team working closely together to achieve well–defined objectives. Tasks, responsibilities and progress are measured and tracked in a series of integrated plans and schedules developed by the contractor and customer to meet the program/system requirements.

Individual managers have access to all plans and schedules and understand how their part contributes to the total program. Progress is measured in formal weekly program reviews with the total program directorate. Other smaller or individual meetings are used to iron out differences of opinion or improve operating procedures.

When expanding technical capability, failures are inevitable and changes must be incorporated. In specific situations, special task teams are formed to develop solutions to critical problems. Progress is reviewed frequently by management, and decisions are made on a weekly or even daily basis for critical problem areas. In summary, individual commitment and performance is at its peak when the team believes in the objectives, recognizes his or her individual responsibility, and shares in the progress towards meeting those objectives.

Contractor~ Customer Relationship

Successful implementation of a Skunk Works management approach requires that the program customer be strongly committed to operating in a similar manner. This should not be a unique management approach: it is a rational way to develop new products containing advanced technology components. The starting point is a small, high quality, highly responsive customer pro-

gram office, and a small supporting organization only as needed. The customer program manager must be given singular authority and broad responsibilities. The program manager should report directly to a senior decision–capable management level free of external "staff" direction.

During the F–117 development, a small Air Force System Program Office (SPO) at WPAFB was augmented by small supporting organizations at Hq. USAF, Hq. TAG, Air Force Flight Test Center – Edward's AFB, Sacramento ALC, and Nellis AFB. This SPO director reported directly to the Commander, Aeronautical Systems Division, who was a Lieutenant General .

Successful development, production and fleet operations were achieved by building mutual trust over time among the contractor, Air Force, and supporting subcontractors. The Air Force and Lockheed program team maintained daily, open communications on program issues which resulted in teamwork, rapid joint problem solving, and mutual trust, rather than adversarial relationships.

Frequent technical and program reviews were conducted, but only important work and decisions were documented. Formal contractor–customer pro– gram reviews were held regularly and keyed to the pace of the program (from every six weeks to every quarter). Small program offices and close, regular communications minimized the need for formal reports, documentation, and more frequent program reviews.

LESSONS LEARNED

Before addressing the Lessons Learned in managing Life Cycle Cost (LCC), the elements of LCC need to be put into perspective. For a manned fighter, the O&S cost is the major element of the 10 year LCC, constituting about 55% of the LCC with acquisition about 40% and RDT&E the remaining 5%. For bomber and transport aircraft, the 10 year O&S cost is more like 65% (due to much more peacetime flying than a fighter), and 30% and 5% for acquisition and RDT&E respectively. The manpower cost to support flying operations is the major cost item in the O&S, constituting over 50 percent. Fuel costs, on the other hand consitute only 12 to 20 percent. For a fighter aircraft the breakdown of the acquisition cost is approximately 50% for airframe, 25% for avionics, 20% for propulsion and 5% for the remainder (crew station, armamaent, etc).

Program Planning

Implement Kelly's 14 Rules

The 14 Rules work ... so use them! The only hitch is that the customer has to agree to use them or they will not work.

Shoot the Cost Estimators

When the program is starting up and cost estimates are being developed, every effort should be made to develop a "bottoms up" cost estimate without using historical data. If you are trying to "break with tradition" and reduce costs, you should not have your cost targets set by esimators using historical cost data bases.

COST is King

The program priorities need to be established at the very beginning and COST better be #1. When "push comes to shove" and things need to be compromised, the program priorities establish how things are going to be traded off. Putting COST #1 means that everything else (performance, signature, etc) will be traded before COST is touched. This priority list has to be ruthlessly enforced, otherwise the performance and signature gremlins will sneak their favorite technologies onto the system and the cost will explode.

Quite often the company culture is that performance or signature is King. In this case there will need to be a cultural change since cost, performance and signatuare are in conflict. Often in the past, the metric was "cost effectiveness" which always meant more performance at the expense of cost (cases of reducing cost at the expense of performance are extremely rare). The cultural change will not be easy for most people and some will never change. Once people agree that COST is King there will have to be an almost daily reinforcement.

LMSW is working on two contracts where the customer established COST as King and is holding to it. The first is the DARPA contract for the low signature, high altitude, long endurance reconnaissance aircraft Tier 3– Darkstar. DARPA is asking for the best altitude, endurance and signature for a unit cost of $10M for units 11 through 20. The $10M unit cost drove the empty weight, interior volume, low signature treatment design such that altitude, endurance and signature was a fall out. The second contract is with the US Air Force for JASSM (Joint Air–to–Surface Standoff Missile). The contract is asking for a unit cost of less than $500K ($1995) for 2500 units. It should be noted that JASSM replaced the cancelled TSSAM (Tri– Service Standoff Missile, AGM–137). TSSAM also had a unit cost of $500K ($1985) and was cancelled in early 1995 when the unit cost increased to $2.3M.

Get the Best People

It is a fact that in any given organization there is small percent of the people that do the majority of the work. If you get the wrong people on the program you are in trouble meeting cost and schedule. For example, it is not uncommon to find a small group of designers that can turn out three times the number of drawings as the average designer.

Design to Empty Weight

Acquisition cost, to first order, is driven by empty weight as shown in Figure 2. This means that as soon as the cost target is established, it should be translated into an empty weight and weight budget. From then on the weight budget is tracked daily and any deviation from the budget is the cause for intense scrutiny.

Tailoring the Specs

Tailoring the specs means negotiating the mission requirements, acquisition requirements and manufacturing specs to give the designer, program manager and manufacturing manager

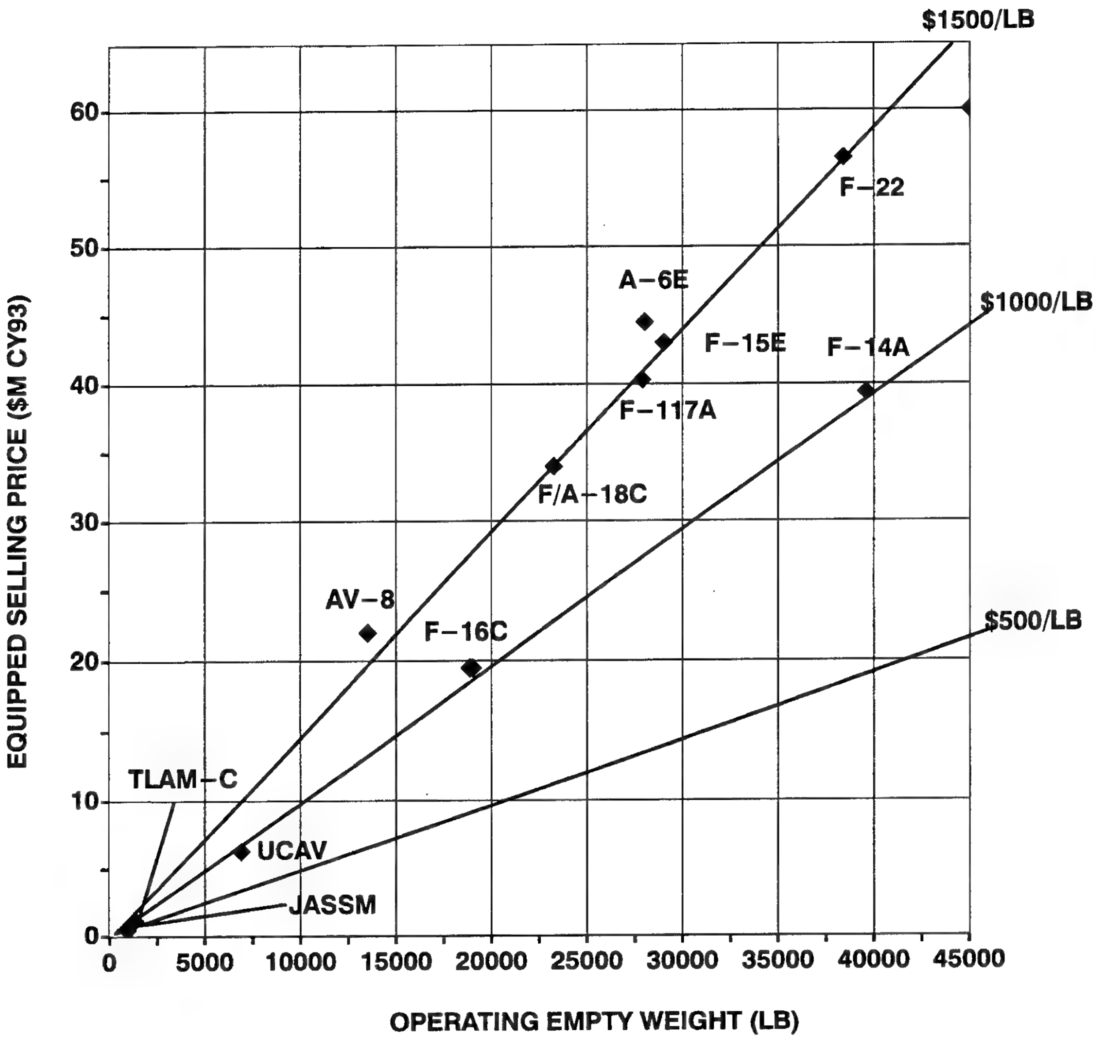

Figure 2 Cost trends for manned and unmanned systems

as much freedom as possible.

The Lockheed Skunk Works' practice is to tailor specifications to meet the unique requirements of a contract. The emphasis is on use of functional specifications defining "what" is to be achieved, and not "how" it is to be accomplished. Size and detail are minimized. Only critical performance parameters are specified as requirements. Peripheral standards and specifications are defined only as guidelines, to the greatest extent possible.

The model spec size in number of pages for Skunk Works aircraft is as follows:

Aircraft	Year of Spec	Spec Size (Pages)
U–2	1954	35
SR–71	1962	54
Have Blue	1975	25

F–117	1977	62
TR–1	1979	91
Tier 3–	1994	1
JASSM	1996	20

The original U–2, SR–71, Have Blue, F–117 and TR–1 model specs were all relatively small and highly tailored as compared to normal procurement programs. However, even within the Skunk Works, there has been a trend away from simple, brief specifications, particularly once a program transitions from specialized management to conventional management procedures. This is believed to be a bureaucratic phenomena and is not, and should not, be inevitable. The Tier 3– is a recent example of a Government trend to return to simple and brief specifications. The one page spec from DARPA on the Tier 3– simply specified best altitude, endurance and signature for a $10M ($94) unit cost for units 11 through 20. JASSM's 20 pages could have been condensed to something less than 5.

The F–117 program is a good example of the Skunk Works tailoring of specifications. The Air Force and Skunk Works focused on the key F–117 weapon system characteristics, and agreed to specifications and warrantees of three critical performance parameters — the radar cross section for all critical frequencies and aspect angles, the weapon delivery accuracy for guided and unguided weapons, and the aircraft mission radius. The F–117 met these specified requirements. The other, less critical performance parameters were defined only as "goals," rather than hard specified numbers.

The mission requirements should be absolutely what is needed and nothing more. Don't make the 3–Sigma, all possible eventualities a requirement without doing the trade study to understand both the cost and benefit. The mission requirements should be balanced so that one requirement doesn't drive the design. And, most important, they should be negotiable and changeable once the "cost" of each requirement becomes known.

The acquisition requirements should be streamlined and require minimum reviews, documentation and approval levels. The funding should be multi–year and cost–type. The contract should never be fixed price (every fixed price development contract awarded in the US during the early 80s has either been terminated or the contractor has lost money). The Skunk Works approach is a good example of tailored acquisition.

Tailoring the manufacturing specs means letting the manufacturing group specify the material and process specs, be a party to establishing tolerances and be able to adopt best commercial practices.

Manufacturing Friendly Design

Manufacturing friendly means that manufacturing personnel are influencing the design daily from the very beginning. The design adheres to the following time–proven guidelines for reducing manufacturing (fab and assembly) hours:

- KISS (Keep It Small and Simple)
- Minimum part count
- Minimum touch labor

- Minimum holes drilled (major source of rejected parts)
- RHS/LHS part interchangeability
- Self locating features on all parts
- Maximize room temperature processes

Keep It Simple is very important. Any complicated feature or new technology must "buy" its way onto the design. Both industry and government have been guilty in the past of inserting technology into a system solely for the sake of technology (making it more modern or state–of–the–art). This practice invariably drives the cost and risk up.

A good example of this is the use of composites. It is very difficult to beat the cost associated with a metal product because of our experience with metal and the associated learning curve. But yet, composites are very often used where there is not a compelling reason (such as reduced weight or increased stiffness). Most of industry would associate a learning curve of about 80 percent for aluminum fab and assembly and 88 percent for composite. This 8 percent difference in learning curve has a powerful leverage over a production run. For example, the cost of the 1000th unit in metal would be 0.11 of the cost of the first unit. For a composite structure with an 88 percent learning curve the cost of the 1000th unit would be 0.28 of the first unit.

Off–The–Shelf Equipment

Using off–the–shelf (OTS, either Mil–Spec or commercial) equipment is very important as it reduces the risk of concurrent development. The form/fit penalty of using OTS equipment needs to be carefully traded with the cost and risk of developing a new item which presumably gives better performance. The rule should be that a new piece of equipment, just like a new technology, must "buy" its way onto the design. This means that the performance gain is substantial or the requirement cannot be met without it. The equipment items that drive schedule and cost are: engines, landing gear, flight control computers and actuators. Avoiding concurrent development is a good rule to follow.

Design For Operation and Support

The operation and support (O&S) cost needs to be reduced by paying careful attention to the maintainance, support and training of the weapon system. Since peacetime training accounts for most of the Life Cycle Cost, the training strategy should receive extensive attention. As much training as possible should be conducted through synthetic environment or simulation and not by actually operating the weapon system. If this can be done, then the aircraft would be maintained in flyable storage resulting in significant savings in peacetime O&S.

Every effort should be made to reduce the manpower required for maintaining and supporting the weapon system. Design for maintainability means having adequate access panels and installing the equipment chest high and one deep. Unique tools need to be minimized. Consideration should be given to future modifications (engine, avionics, weapons, etc) and design accordingly with easy access, extra volume and growth power capability.

Prototypes and Technology Demonstrators

The merit of prototypes and technology demonstrators in terms of reducing the overall program cost has been the subject of heated discussions for decades. There are circumstances where prototypes and technology demonstrators have considerable value in terms of proving a concept or validating a critical system feature, such as maneuver performance or vehicle separation. Other circumstances such as validating production cost or weight, prototypes have little value unless they duplicate the production structural design, fab and assembly ... in which case they could hardly be called prototypes.

Concurrent Engineering or Integrated Product Development (IPD)

Concurrent engineering or IPD is a systematic approach to the integrated design of products and of their related processes, including manufacturing and support functions. The "manufacturing friendly" design discussed earlier demands the in–depth participation of manufacturing from the very beginning of the design process. The design process needs to be carried out through integrated work teams with the participation of all the involved functions. This means having everyone involved in the early design when the cost of a design change is small so that the design changes during EMD and production are few (when the cost of design change is large).

SUMMARY

In order to manage a weapon system's cost you must first establish cost as the #1 priority and then incite the program manager and give him the means necessary to hold to the cost. Establishing cost as #1 is a company edict and may require a cultural change. The program manager must be a zealot about cost because he will be pressured daily to relax cost in favor of more traditional metrics (ie; performance, cost effectiveness, signatuare, etc.). Kelly's 14 Rules gives the program manager the authority and environment necessary to control the cost.

'COTS' - Customization, Opportunities and Trade-Offs

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BACKGROUND

The requirement for a Utility Tactical Transport Helicopter (UTTH) fleet is derived from the roles of the Canadian Forces and the specific missions assigned to the Land and Air Forces. In general, UTTH resources can be called upon to conduct operations in any of the following general mission areas:

a. Operational and training support to the land forces and other CF organizations;

b. International peacekeeping operations; and

c. Operations in aid of the civil authority.

Other unique missions include:

a. Fire-fighting operations to include water bucketing;

b. Administrative airlift of personnel and equipment;

c. Reconnaissance and surveillance in support of civilian agencies;

d. Support to civil authorities including special operations; and

e. Secondary search and rescue (SAR) response.

To maintain this capability in the Canadian Armed Forces (CF) beyond the mid 1990s, significant expenditures were necessary to either retrofit existing fleets or to replace them. In September 1992, the Minister of National Defence (MND) announced that a contract had been awarded to Bell Helicopter Textron, Canada (BHTC) for 100 helicopters. Designated the CH146 Griffon by the CF, the Bell 412CF (the civil designation) is a 15-place aircraft powered by the Pratt and Whitney of Canada, Ltd. (P&WC) Model PT6T-3D twinned turbo shaft engine.

AIM

The aim of this paper is to describe the methods by which the CF balanced a commercial off-the-shelf (COTS) process by customization, opportunities and trade-offs (also COTS) as an example towards meeting the cost challenges of the 21st century.

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

SCOPE

This paper will present a description of the specific customization efforts and associated trade-offs as they apply to the CH146 acquisition and fielding. It will not focus on cost benefit opportunities *per se* as these issues have been discussed in a previous paper (reference A). Some repetition of information will be unavoidable in illustrating opportunities achieved in the CH146 helicopter acquisition and introduction into service. Nor is it intended to discuss the decision making process resulting in the opportunity to acquire a common fleet of helicopters to replace three to four types of aircraft. The comparative arguments should allow the reader to make his or her own conclusion in respect of the ability of this aircraft to meet challenges of the future in your own individual programs.

COTS/MOTS - A DECISION

While the thesis of my paper focuses on a slightly different interpretation of the COTS acronym, it is also necessary to discuss the Military off-the-shelf (MOTS) approach. Traditional military aircraft procurement normally invokes the use of military specifications and standards to ensure a quality weapons system that is not only safe and survivable but which is also durable and meets minimum flight performance requirements essential for mission accomplishment. Canada's purchase of military helicopters in the past : COH-58A, UH-1H and CUH-1N, has been through Foreign Military Sales - a nominal Military off-the-shelf (MOTS) approach to which we would add a few minimum requirements during aircraft production (the 'C' designation indicates an addendum to the US military specification). Canada also directly purchased a commercial model: a Bell 206B, in support of training - a true COTS approach. While previously operated under military registration, these aircraft are now civil registered (special category) under a leasing arrangement in support of contracted military pilot training. Thus, as stated at references B and C (albeit specific to avionics), there is an increasing reliance on the commercial off-the-shelf philosophy in government and defence industry and on those practises and processes used in the 'commercial' world. The CFUTTH project mandate was clearly based on COTS principles in that "to the maximum extent possible, only 'proven off-the-shelf, in-production equipment' (would) be considered for the CFUTTH". While this applied to both the commercial and military aspects of the program and was therefore a partial MOTS approach, the prime mission vehicle, the 412CF, is truly a commercial product regardless of its lineage or end use.

The approach to the CFUTTH acquisition resulted from a 1991 internal options study to ensure achievement of

optimal acquisition and support economies. The study aims focussed on validating the operational requirement (SOR), assessing various options against the SOR, and examining procurement and support alternatives. The cost and benefits analysis of each option led to the conclusion that a single fleet offered many operational benefits including improved capability to conduct national and international tasks, elimination of cross-training inefficiencies, improved standardization and interoperability, enhanced operational performance and improved survivability. It was also concluded that the most economical ownership option would be through direct acquisition of new, civil certified helicopters and, that the Bell 412 was significantly lower in cost than other compliant helicopters assessed.

From a philosophical perspective, I could well argue that the CFUTTH program was a leader in government change initiatives rampant in the 1990s. Such Canadian initiatives as Alternate Service Delivery announced in the Defence White Paper of 1994, or US SECDEF William Perry's 1994 Best Commercial Practices Initiatives contain remarkable similarity to the CH146 acquisition effort. The Canadian government decision in 1992 to procure a CFUTTH was an embarkation towards different ways of doing business and significantly influenced project prosecution. A COTS product often implies a Non-Developmental Item; the CFUTTH is a customization of the Bell Model 412, a proven commercial product requiring some level of effort to ensure the integration of specified equipment to meet military requirements, arguably a minimum degree of development *per se*. The original equipment manufacturer's (OEM) need to translate the military standards and specifications into that used for their production aircraft was reduced substantively and this can be expanded to included processes necessary for delivery and follow-on support. While some examples will follow later, it is fair to say that the level of effort on the part of all involved was correspondingly reduced, but do not interpret this to imply that management of such an activity is simple for it remains rather complex. Thus the opportunity of reduced process time to contract award, the corresponding smaller number of personnel in the management of the project on both sides of the inevitable contract, good focus, and a greater reliance on partnership or teaming. The potential trade-off is that, amongst other factors, a small management staff cannot address all the issues at the same time and there is associated increase in risk with respect to schedule and product quality - the challenge of any program.

From the outset, the decision to adopt a civil-based helicopter not only affected the prime mission vehicle selection, it also influenced most other project elements. It impacted the selection of avionics equipment, mission kits and the approach to maintenance and supply

support. A "commercial" theme was adopted challenging the traditional military way of doing business. This theme permeated the work environment as the often heard phrases attest: "We're just another commercial customer" and "If it's good enough for the civil operators, it's good enough for us". This propensity is, in my opinion, the only manner by which one can truly invoke change and take full advantage of alternative approaches to product delivery but one which must be balanced by selective reasoning and good planning.

CERTIFICATION/ AIRWORTHINESS

As an example of the commercial practices adopted, the CFUTTH contract required that the OEM provide a civil certified helicopter albeit a product being acquired for military use; a process not unlike the C-130J and the company (Lockheed) funded effort for an amended FAA 382G type certificate. However, there is one distinct difference, the C130J is a civil certification in parallel with the military product development, the CFUTTH requires that civil certification been an integral part of the product delivery. Acceptance of civil certification avoided the traditional cost drivers of other military procurement initiatives as noted later; it established a mechanism whereby the Contractor was able to introduce a product into service in a manner similar to delivery of all of his products. The US Federal Aviation Agency (FAA) 412CF Type Certificate (TC) assures a standard of airworthiness and safety of flight; Transport Canada inspects every aircraft to ensure conformance of the product to the type design. A real opportunity presented itself herein as these other Government Departments/Agencies performed tasks critical to the delivery of the 'civil' product as required to support an OEM without the additional miltary presence. There are currently no 412CF aircraft intended for civil registry; only the Canadian Forces has purchased the 412CF to date and these will be operated under a Canadian Military Airworthiness Type Certificate (CMATC). This is the trade-off that must be accommodated as future efforts by the government agencies will be minimized in post production support activities. As but one example, FAA will now only consider changes to the FAA approved Flight Manual which impact on safety of flight with revisions of any other nature requiring CMATC approval. The process and resources to accomplish this type of follow-on support are not insignificant and will require a teaming effort with the OEMs and the Canadian Forces. Please note that it is the intent of the Weapon System Manager to mitigate unique requirements for support by maintaining product integrity and commonality with the 412 model aircraft. As such, FAA, TC and the OEMs will still be providing a level of support consistent with the need to assure safety of flight for all customers, commercial or military - sort of an 'arms length' approach to military 412CF

aircraft with respect to direct applicability and enforcement.

Returning to the opportunities of the adopted civil based (commercial off-the-shelf) process from a project perspective, the amount and scope of the OEM flight test and evaluation program were significantly reduced based on a proven track record and aided in keeping program costs down. The certification of non-civil equipment required less direct military involvement as military items were cleared for carriage on a non-hazard basis. The operational test and evaluation of the helicopter and system performance was conducted "in-house" with associated certification and qualification of CH146 unique military systems. Overall, the level of effort was reduced substantially. Similarly, government quality assurance (QA) staff at the manufacturer's facility was restricted to one officer as required to accept the product in order that payments could be authorized. We adopted the civil approach stated earlier, civil inspectors on-site issued a civil certificate of airworthiness for each helicopter with no requirement for military QA. This included flight tests by the OEM, a departure from the traditional flight verification conducted by a qualified military test pilot(s) for each aircraft. Some would argue that we have lost control of the product quality; the counter is that we have now been able to hold the contractor liable for the quality of the product. The advantage and disadvantages are a function of the program and the partnership. As the CF has owned and operated several Bell helicopter models, it is fair to say that the risk in this partneship were minimized by our experience.

CUSTOMIZATION

The COTS/MOTS trade-off is truly exemplified in the degree of customization of the end product required. Traditional aircraft purchases always permit certain options in the final product - eg. a Boeing 777 would have different engine or avionics options, both of which would be provided by the OEM based on the customer's direction. The 412CF customization effort was integrated into the 412 model vehicle design specification and relies on a principle of minimal customization with one baseline configuration (military and commercial requirements) supplemented by mission kits - some military, some commercial.

All aircraft share a common camouflaged, low infrared reflective paint scheme - note that this scheme was retained for all aircraft irrespective of role and the five recently painted white for a United Nations deployment departed from the traditional all white aircraft to a partial doors, nose and tail fin white paint scheme. In addition to the standard Bell Model 412EP features, all are equipped with dual controls, a wire strike protection system, a rotor brake, external/internal crew door jettison handles, a cargo hook, crew seats

with integral lumbar support, transmission gearbox chip detecting system with fuzz burn off, and a heavy duty heater. All aircraft have a Solid State Cockpit Voice Flight Data Recorder (SSCVFDR) and rotor track and balance as the first step in a full Helicopter Health and Usage Monitoring system (HHUMS) implementation currently underway. All have modified landing gear and other support equipment to ensure air transportability via the CC130 Hercules aircraft - a military requirement. Other modifications include a crashworthy self sealing fuel system, a data transfer system and an emergency control panel. For the most part, the aircraft lighting, including instruments, interior and exterior lighting, as well as the interior paint scheme are Night Vision Imaging System (NVIS) compatible. In normal operations, the CH146 employs two pilots and a flight engineer with a SAR technician for search and rescue operations.

The approach employed in respect of mission kits is an excellent example of the theme of this paper. All aircraft are fitted for but not with the range of mission equipment offering employment flexibility and a reduction in the number of kits normally purchased. The kits procured for this aircraft include: external rescue hoist, Forward Looking Infrared (FLIR), spotter window kit, auxiliary fuel tanks, survival kit for SAR operations, lightweight armour protection, pilot and co-pilot armoured seats, Nitesun searchlight, HF radios, skis, and 6 person litters. The tactical aviation squadrons and combat support squadrons (CSS) differ only in the mission kits normally employed.

AVIONICS MANAGEMENT SYSTEM

One area that required some development was the Avionics Management System (AMS) which integrates the navigation, communication, identification (IFF/SIF) and aircraft survivability (ASE) sub-systems, some items of which are also treated as kits. This was required to address cockpit space and weight constraints, and to provide for future growth. While it was necessary to deviate from the avionics suites typical in the commercial world, readily available military and commercial products were selected. The MOTS approach (refer to the manner in which the term is applied as presented previously) was employed in respect of the Cockpit Display Units as they were developed from the US Army Pavehawk program by the OEM - Canadian Marconi Canada (CMC). Two CMA-2082 Control and Display Units (CDU) are the core computers for the AMS and employ a dual-D MIL-STD-1553B data bus and ARINC 429/582 serial lines as the prime means of data exchange and control with the various sub-systems. A CMA-2060 Data Transfer System and an Emergency Control Panel also provide operator interface. Some of the avionics

equipment controlled by the AMS include: dual AN/ARC-210 Multiband Radios; single AN/ARC-164 UHF(AM) Radio; triple KY-58 Vinson Voice Encoder; single AN/ARC-217HF Radio; single ANDVT TACTERM Voice Encoder; AN/ARN-147 VOR/ILS/MKR; AN/ARN-149 LF-ADF; AN/APX-100 IFF; KIT-1C Mode 4 Encoder; CMA-2012 Doppler Velocity Sensor; Collins MAGR Global Positioning Sensor (GPS); Threat Warning System (type yet to be determined); AN/ALE-39 Counter Measure Dispensing System; AN/AAR-47 Missile Approach Warning System; AR-335 Radar Altimeter (Dual Display); and DM-442 Distance Measuring Equipment. The AMS is also interfaced with: dual Sperry 7600 Digital Automatic Flight Control System (3 Axis combined Autopilot and Flight Director); dual Three-axis Reference System Directional Gyro and Vertical Gyro (TARSYN DG & VG); dual Electro-mechanical Vertical Situation Indicators (ie ADI's); dual Electro-mechanical Horizontal Situation Indicators; and Map Display Unit (in process). I would dare say that references B and C do more justice to the subject of avionics integration and it is fair to say that this was one area of risk in the project. This risk has been managed successfully to date but there still remains a fair level of effort to include performance of some of the "unique" military equipment such as communication and aircraft survivability equipment. This equipment was cleared for carriage on a non-hazard basis by civil standards but the requirement to certify and qualify the products remains a military responsibility. The solution in light of Intellectual Property rights, unique applications, obsolescence potential, and overall complexity will necessitate a team approach to include the OEMs of the equipment and the helicopter and the military. Some will argue that this could be considered an opportunity for further development by the contracted entities; others would advise it to be a trade-off in that the CF has yet to achieve a satisfactory end state having accepted a product that functions after several iterations (currently version 8.0 of the software) with still more to be done.

SUPPORT CONCEPT

In the past, the Department of National Defence (DND) policy concerning support to operations was for total self-sufficiency anywhere in the world and mandated use of its pre-established support structure and organization for purposes of autonomy. DND's traditional approach in providing supply support to a new piece of equipment had been to initially provide two years worth of consumables and a lifetime of repairables upon introduction into service. The often long procurement lead times forced high stock levels and significant warehousing requirements at all levels and potential stock obsolescence. DND managed the inventory via the Canadian Forces Supply System (CFSS), coordinated transportation through the Central

Movements Transportation and Traffic organization and provided shipment to deployed sites via military means.

From the start, this project acknowledged the existance of Bell Helicopter's worldwide after-sale product support network and its existing commercial support structure. We were committed to validate and employ this approach when deciding how to best satisfy the various support elements whenever practical. CFUTTH initial sparing was reduced to meet anticipated current usage only and relies on Bell and other original equipment manufacturers to provide replacement stock as required. In-service spares management uses the existing Bell Customer On-line Order Processing system, or CO-OP for short. The CO-OP system includes modem access worldwide for deployed operations, real time access to Bell and CF inventory, demand capability at unit level, and a closed loop system for DND-owned repairables. Some features of the contracted support include a specified level of service similar to all other commercial customers, warranty administration and buy back of both excess and obsolete parts. CO-OP is also used for the acquisition and management of parts acquired from other OEM approved sources. The ability to track usage and expenditures to individual helicopters and squadrons as well as locating critical serial numbered components allow for better fleet management decisions.

There is a concurrent reduction in administrative overhead as there are minimal personnel dedicated to CFSS inventory management and none required for cataloguing. The reduced initial provisioning provided immediate capital savings and eliminated the cataloguing activity for thousands of line items as well as reduced inventory levels and shortened procurement lead times. This may be traded-off against a future purchase of spares and repairables, but perhaps will be a decision based upon a greater understanding and knowledge base. As inspection authority for spare parts is vested with civil authorities, minimal military personnel are needed for this function. Shipment is direct to and from squadrons (including support to deployed assets); with no intermediate organizations involved and through the use of commercial shipping such as Purolator and Fedex if priority delivery were required. Here again is another example of an opportunity or trade-off depending on your point of view and acceptance of the culture change mandated by governments of today in finding other ways of doing business while ensuring core military activities are retained.

TRAINING PROGRAM

It is also worthy to note that ab-initio training was contracted with Bell Helicopter for both aircrew and support personnel and some of that continues today. I view this as an opportunity to interact with commercial counterparts

and understand alternative ways of doing business; others would argue that there were trade-offs made as military training standards were not always met. For information purposes, the end state for regenerative training will be 'in-house' for aircrew and maintenance personnel - an opportunity or trade-off based on the premise that some partnership could be viable or not? In order to accomplish this task, several training aids have and will be acquired, to include a Composite maintenace Trainer and support to Computer Based Training. The most significant traing aid is a flight simulator currently up and running at our Operational Training Unit. This was procured through Bell Helicopter Textron Canada (BHTC) as the prime and Canadian Aviation Electonics (CAE) as the sub-contractor. One of the more interesting, but less important details, is that this procurement strategy also made BHTC responsible for the construction of the building to house the simulator - an opportunity not to be missed by a helicopter manufacturer.

MAINTENANCE PROGRAM

Having adopted the civil approach to parts procurement and management, DND also accepted the recommended OEM overhaul intervals for repairables. The following table provides a comparison of major components overhaul times between the CH135 Twin Huey lives in use at time of fleet retirement and the CH146 Griffon helicopter fleet.

COMPONENT	CH135	CH146
POWER SECTION	3500	4000
MAIN TRANSMISSION	1800	6000
MAST ASSEMBLY	1500	5000
DRIVESHAFT	1200	5000
TAIL ROTOR GEARBOX	2400	5000
COMBINING GEARBOX	3500	5000
HANGAR ASSEMBLY	1200	5000

Overhaul Interval Comparison

The difference in overhaul intervals for the CH135 fleet is mainly attributable to fatigue life calculations which provided added safety margins to those already accounted based on military usage assumptions; somewhat self-imposed. While some may argue that this is not a fair representation of an opportunity; the COTS approach would propose that unique military requirements do not necessitate, in all cases, the application of other life limits than those applied to the civil sector. While it is the intent to not depart from the civil standard, there is currently one example of variation from the norm based on a military requirement. A reduction in life of the mast assembly from 10,000 hours to 5,000 hours had to be invoked for slope landings; a 'military requirement which may or may not be fully beneficial but is currently being reviewed for applicability to the commercial 412 fleet. The

potential for further adjustments does exist. While every effort is being made to adapt to the principles upon which the aircraft was introduced into service, it is fair to say that certain military requirements will cause re-evaluation. The current introduction of door guns was specifically rejected at the commencement of the program but has since been introduced into service in support of peace keeping operations in Haiti. While no adjustment to component lives has been made for this door gun installation, there is a limitation to the V_{NE} (never exceed speed) of 100 knots with doors open and mission kits installed. The next step is to increase this V_{NE} to 120 knots to meet the military operational requirement; an endeavour which will, in all probability, result in further testing and some method of component life reduction. This, in my opinion is the classic example of the trade-off type decisions necessary in customizing a product for a required role, not all of which are definable at the beginning of an acquisition program.

The maintenance program for the CFUTTH is based on the OEM recommended maintenance requirements. All first and second level of maintenance is carried out by CF technicians and aircrew whereas third level is carried out by industry as a matter of Canadian Government policy. The opportunity to employ a fully contracted maintenance support philosophy was rejected by the 1991 study due to potential reduction in mobility, deployability and flexibility; however, assistance is readily available from BHTC and P&WC Customer Service Representatives on site or at deployed locations. In addition, a single fleet acquisition provided opportunity for the savings and efficiencies inherent in a common fleet approach for 1st and 2nd level maintenance by CF personnel. While other rationalization activities complicate a calculation of the direct savings, it is safe to conclude that significant maintenance personnel reductions have and will continue to occur.

Another maintenance element is the introduction of Helicopter Health Usage and Monitoring System (HHUMS), a commercial endeavour that is seeing significant military application. Our system currently permits rotor track and balance during a mission and will soon be expanded to support vibration diagnostics for engine and drive train trouble-shooting. While there was no doubt of the basic requirement for this type of system, we traded-off on introduction of a full blown system still under development pending the opportunity for the system to be a little more 'proven' but remain in a 'lead the fleet' status. The SSCVFDR (Solid State Cockpit Voice and Flight Data Recorder) installed in accordance with commercial standards, was not previously required for Canadian military aircraft albeit that policy is currently changing. The provision of data for analysis and investigation is an opportunity for the operator and maintainer as well as the

investigator. As a result of lessons learned from our first accident in Northern Labrador in November 1996, it is probable that we will add to the current minimum data requirements as specified by FAA in order to provide our personnel with a better investigative tool for accidents as well as maintenance trouble shooting.

IN SERVICE

The CF has taken delivery of 90 of 100 helicopters over a 28 month period on schedule and under budget. The CH146 Griffon has flown over 30,000 hours in operational and training units in Canada and a United Nations deployment in Haiti. The versatility of the aircraft in a variety of tasks has been proven during flood disaster relief efforts in Manitoba and Quebec in the past year and support to special operations. Two of a total of nine squadrons remain to be fully complemented. Operational availability is averaging 75% for all units, a reasonable figure at this stage of introduction into service. While it is fair to say that the operational requirements as defined at the outset have been met, it is also valid to note that some not insignificant effort remains in order to obtain the optimum utility of this aircraft in its full spectrum of roles. As Project and Weapon System Manager responsible for completion of the acquisition and sustainment, I could only say that the team has been presented many an opportunity, some exciting, some frustrating and yet opportunities for improvement still remain, along with the odd trade-off consideration.

SUMMARY

An assessment of all available options and commitment by the decision makers assured that Canada would maintain a utility tactical transport helicopter capability well into the 21st century. Acknowledgement of civil expertise with the adoption of the civil helicopter certification as a basis for a military fleet took advantage of an opportunity that enabled the timely delivery of aircraft and provided a number of cost benefits.

The Canadian Forces Utility Tactical Transport Helicopter project is viewed as a best practise in its ability to deliver an "affordable *combat* aircraft" for the military role assigned and an excellent example of partnership between government and industry. While variations on the theme are required in accommodating the constraints imposed on individual projects, this paper concludes that COTS, an acronym for commercial off-the-shelf must be balanced with another COTS of customization, opportunity and tradeoff in order to meet the cost challenges of the 21st century.

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Leçons à tirer de la dualité civil/militaire : exemple de SAGEM *SA*

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RESUME

SAGEM *SA* est une entreprise duale au sein de laquelle les fabrications d'équipements militaires bénéficient d'un outil industriel et de compétences partagés avec les activités civiles. Une enquête réalisée dans ces secteurs a cependant permis de dégager des points durs générateurs de surcoût pour les équipements militaires. L'analyse de ces points montre que le contexte de l'expression des besoins et les organisations industrielles sont davantage générateurs de surcoût que les contraintes spécifiques du militaire.

A partir de ce constat, de nouvelles façons de procéder sont proposées. Elles ont pour objectif principal de créer un environnement favorable à la Conception à Coût Objectif chez les industriels grâce à une bonne connaissance du marché, un accès à l'utilisateur final, l'appel aux propositions d'optimisation, et grâce à la définition de sous-systèmes permettant d'organiser la concurrence.

En retour, cet environnement sera d'autant plus porteur de baisses de coût qu'il s'adressera à un industriel tirant partie de la dualité de ses activités ; mobilités des personnels entre les différents secteurs, valorisation des métiers horizontaux, saturation des moyens de production.

1 INTRODUCTION

C'est une idée aujourd'hui communément admise de pouvoir réduire les coûts dans le secteur de la Défense en s'appuyant sur les technologies civiles voire en s'inspirant des méthodes du secteur civil.

La coexistence au sein d'une entreprise duale comme SAGEM *SA* d'activités civiles et de défense offre l'opportunité d'aller plus loin dans cette analyse et d'identifier les différences génératrices de surcoût comme celles qui représentent un frein à l'introduction des nouvelles technologies.

Pour débusquer ces différences, un groupe de travail est allé sur le « terrain », avec des questionnaires types, pour recueillir les réponses de responsables dans tous les secteurs de SAGEM *SA*. C'est ainsi que des « points durs » et des « suggestions de nouvelles façons de procéder » se dégagent de cette enquête.

Cette approche a l'intérêt de faire ressortir des différences de fonctionnement avec les secteurs où les contraintes de coût sont particulièrement fortes et nous les présentons sans censure particulière. Nous n'ignorons cependant pas que le contexte des affaires de Défense puisse être notablement différent de celui que connaissent les autres secteurs et ceci à plusieurs titres :

- les missions de défense ne s'expriment pas uniquement sous forme économique,
- le « marché » des matériels militaires et notamment la concurrence se présentent de façon spécifique.

Il faut donc prendre les éléments d'information ci-après comme autant de voies à investiguer, et non pas comme la liste de « ce qu'il faut faire » ou de « ce qu'il ne faut pas faire ».

2 ANALYSE DE L'EXISTANT

De façon à couvrir l'ensemble des phases de vie des produits, l'approche a consisté, pour cette analyse, à recueillir des informations auprès de différents responsables du développement des produits, qu'il s'agisse de représentants de services technico-commerciaux, de recherche et développement, de fabrication ou de maintenance, et ceci dans les trois divisions que sont la Division Défense et Sécurité (DDS), la Division Électronique (DE) et la Division Terminaux et Télécommunications (D2T) de SAGEM *SA*.

Les produits audités ont été choisis pour leur représentativité d'un type de marché (type de client, quantités/cadences, sévérité des environnements) et d'une phase de vie (expression du besoin, spécifications, prototypes, série, maintien en conditions opérationnelles). Par ailleurs, s'agissant des produits du secteur Défense, la liste des produits audités comprend aussi bien des produits développés dans le cadre de financements étatiques que des produits développés sur fonds propres pour le marché export.

2.1 Produits des secteurs civils

- La gamme de FAX,
- Les compteurs électriques pour EDF,
- Les calculateurs d'injection pour automobiles,
- La gamme de terminaux GSM.

2.2 Produits du secteur de la Défense

- Des caméras thermiques,
- Des centrales inertielles,
- Le boîtier électronique de contrôle-moteur du char Leclerc,
- Le système de drônes Crécerelle,
- Des conduites de tir pour char,
- Des références inertielles de satellites,
- Un FAX sécurisé,
- Des viseurs gyrostabilisés,
- Des systèmes de préparation de mission (produits à dominante logiciel),
- Modernisation d'avions.

De façon à cibler les questions en fonction des responsabilités des personnes interrogées, ce n'est pas un questionnaire mais 6 questionnaires qui ont été réalisés :

- Questionnaire 1 : Définition du besoin
- Questionnaire 2 : Établissement des spécifications
- Questionnaire 3 : Techniques mises en oeuvre pour concevoir le produit
- Questionnaire 4 : Développement et réalisation des prototypes
- Questionnaire 5 : Production
- Questionnaire 6 : Maintien en conditions opérationnelles

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

3 POINTS DURS

Le dépouillement des audits pour chaque produit et chaque étape du développement a permis de dégager **71 « points durs »**. Un groupe de travail composé de représentants des différents secteurs de SAGEM *SA* a hiérarchisé ces différents points durs et les a regroupés par thèmes :

3.1 Contexte de l'expression du besoin	**459**
- Manque d'accès aux opérationnels pour reboucler les spécifications	88
- Pas de définition à coût objectif	73
- Situation de monopole	50
- Expression de besoin exprimée sous forme de solutions	38
- Pas de prise en compte des marchés export	25
- Non prise en compte du MCO dès le départ du développement	25
- Budgets mal connus au départ	25
- Spécifications imposées en limite technologique	20
- Produit se révélant surabondant en fonctions et/ou performances	20
- Manque d'appel aux propositions d'optimisation	15
- Re-spécification de produits existants	15
- Manque de points de contacts techniques à la DGA	10
- Manque de rebouclage de la définition du MCO sur l'utilisateur final	10
- Pas de possibilité de réaliser une Analyse de la Valeur	10
- Spécifications trop détaillées	10
- Ne pas savoir pratiquer de "mid-life update"	10
- Réparation "coûte que coûte"	5
- Impact important de l'ergonomie sur le coût	5
- Bancs de soutien universels pas toujours adaptés	5

3.2 Organisation industrielle	**260**
- Organisations industrielles complexes	55
- Architecture produit liée à l'organisation industrielle	55
- Maîtrise d'oeuvre non justifiée	55
- Manque de définition du futur rôle de l'industriel pour la maintenance	25
- Financements différents de l'acquisition et du MCO	20
- Délai et distorsion dans la répercussion des décisions prises par le client à travers les maîtres d'oeuvre	15
- Organisation industrielle de la maintenance non fondée sur l'optimisation des coûts	10
- Marges prises sur les spécifications par les maîtres d'oeuvre pas toujours justifiées	10
- Informations insuffisantes accompagnant les retours pour réparation	5
- Traitement administratif des réparations trop long	5
- Sous-traitances imposées	5

3.3 Contraintes spécifiques	**195**
- Choix de composants en listes GAM	30
- Normes et standards spécifiquement militaires	30
- Contraintes spécifiquement militaires	30
- Doublement des essais de recette pour cause de surveillance étatique	25
- Suivi et surveillance étatique	25
- Surcoût des expertises de l'organisme de surveillance en début de programme	25
- Standards franco-français utilisés pour la spécification du produit	15
- Classification pour sécurité militaire	5
- Exigences de propriété intellectuelle	5
- Fourniture de dossiers de conception trop détaillés	5

3.4 Management	**131**
- Qualification réalisée trop tard	31
- Découpage des marchés/gestion par tranches annuelles/glissement des délais	15
- Durée de développement trop courte par rapport à l'expression du besoin	10
- Industrialisation obsolète et à refaire à la date réelle de fabrication	10
- Qualifications doubles ; par l'industriel et par le client	10
- Surcoût lié à l'arrêt et au redémarrage de production	10
- Décisions client non prises à temps	10
- Spécifications incomplètes ou évolutives	5
- Évolutions pour baisse de coût très filtrées	5
- Manque d'études en amont pour réduire les risques	5
- MCO par tranches conditionnelles	5
- Obsolescence des COTS (PC par exemple)	5
- Surqualité pour assurer la qualification dans le cadre de délais très tendus	5
- Non maintien des compétences si MCO non prévu	5

3.5 Conséquences des faibles quantités	**85**
- Etudes amorties sur un trop petit nombre d'exemplaires	15
- Quantités et projets non fiables	15
- Quantités faibles	15
- Coût élevé du traitement des obsolescences	10
- Surcoût lié au nombre élevé de variantes	10
- Phase d'intégration/recette relativement coûteuse sur les petites séries	5
- Nombre important de postes de fabrication à équiper	5
- Surcoût lié aux quantités mini d'achats de certains composants	5
- Pas de préséries pour cerner les problèmes résiduels	5

3.6 Méthodes	**70**
- Référentiel de coûts insuffisamment fiable ou biaisé	15
- Couplage "étude/fab" moins efficace dans le secteur militaire	15
- Pratique insuffisante de l'analyse des produits ou technologies concurrents	15
- Recours à la sous-traitance non orientée "coût"	10
- Habitude de faire un maximum de choses soi-même	10
- Critères de qualité internes spécifiquement militaires	5

On constate que le manque d'accès aux opérationnels pour optimiser les spécifications apparaît au plus haut niveau de cette hiérarchisation, de même que plusieurs autres points touchant aux conditions nécessaires pour réaliser des Conceptions à Coût Objectif.

Les points durs concernant les organisations industrielles et les maîtrises d'oeuvre arrivent globalement au second rang pour ce qui est de l'impact sur les coûts.

Les contraintes diverses liées aux spécificités des programmes militaires (normes, standards, composants, surveillance...) figurent globalement au troisième rang des points durs générateurs de surcoûts.

4. ANALYSE DES POINTS DURS

4.1 Contexte de l'expression du besoin

On trouve dans ce domaine tous les points durs qui, au départ des affaires, limitent l'efficacité dans la recherche du meilleur compromis qualité/prix (ou Valeur/prix au sens de l'analyse de la valeur).

Parmi tous les domaines abordés, c'est vraisemblablement celui qui a le plus d'impact sur les prix tant il est vrai qu'il joue directement sur les choix fondamentaux qui seront faits dans la conception des produits.

On trouve donc dans ce domaine des points qui concernent la relation entre les services techniques, l'utilisateur final et les fournisseurs potentiels.

D'une part, l'expression de besoin ne peut être faite sans prise en compte du marché (et pas seulement hexagonal) dans lequel le produit évolue : prix de marché et évolution, situation concurrentielle, possibilités offertes par les technologies, prise en compte de l'existant, possibilités d'export, possibilités d'applications connexes (par exemple dans d'autres armes que dans celle où est exprimé le besoin).

D'autre part, le processus devant permettre d'affiner le cahier des charges pour réaliser une conception à coût objectif nécessite une approche dynamique dans laquelle :

- l'expression de besoin ne peut pas être figée dans des solutions prévues à l'avance,
- on ne peut se passer des contributions créatives des différents industriels intervenant dans un contexte concurrentiel,
- on ne peut se passer de l'utilisateur final pour reboucler à tout moment l'incidence des orientations prises,
- on ne pourra pas maîtriser le coût global sans avoir exprimé un besoin incluant le MCO et notifié un contrat global.

4.2 Organisation industrielle

SAGEM *SA* intervient à différents niveaux industriels en fonction des activités et des marchés concernés ; fournisseur de composants, fournisseur de sous-ensembles, fournisseur d'équipements, maître d'oeuvre et fournisseur de sous-systèmes, maître d'oeuvre de systèmes.

Cette expérience conduit la plupart des personnes auditées à exprimer des points durs relatifs aux conséquences d'organisations industrielles non dictées par une logique de coûts.

Cela concerne en particulier les organisations complexes, qui multiplient les interfaces, conduisent à des spécifications en limite de technologie pour les composants, diluent les responsabilités, induisent une gestion lourde et génératrice de délais.

Cela concerne aussi les maîtrises d'oeuvre en situation de monopole et tentées par l'intégration verticale : désir du maître d'oeuvre de s'engager sur des métiers nouveaux au risque de faire supporter au programme l'apprentissage.

La systématisation de la maîtrise d'œuvre, quel que soit le niveau de la démarche, est également génératrice de surcoût.

Cela peut également concerner le rôle des opérationnels dans le cadre de la maintenance.

4.3 Contraintes spécifiques

Par rapport aux autres marchés, le marché des produits militaires impose de nombreuses contraintes ou exigences spécifiques. Nombre d'entre elles sont justifiées par le caractère particulier de la mise en oeuvre des matériels et s'expriment dans des standards ou des normes. L'application systématique de ces standards, surtout lorsqu'il s'agit de contraintes spécifiquement françaises, peut être lourde de conséquences sur les coûts, nuire à la compétitivité à l'export, et constitue en tout cas un frein à l'introduction des nouvelles technologies, en particulier celles en provenance du secteur civil.

Les exigences concernant les dossiers de conception et la propriété intellectuelle (notamment des logiciels), génèrent des travaux spécifiques et peuvent être un frein à l'investissement par les industriels dans des modules réutilisables.

Au chapitre des contraintes spécifiques on note également la surveillance étatique exercée sur le terrain et se traduisant souvent par des essais doublés et des lenteurs dans le traitement des évolutions.

4.4 Management

Par comparaison avec le cycle de vie des produits des divisions « civiles » de SAGEM *SA*, le découpage et la dilution dans le temps des marchés militaires apparaissent comme un frein à l'optimisation des solutions et un surcoût global :

- d'une part l'ingénierie simultanée ne peut être valablement pratiquée si les phases d'industrialisation et de série sont découplées des phases d'étude et de développement des prototypes. D'ailleurs la pertinence des solutions retenues dans ce domaine en se projetant dix ans plus tard est discutable puisque l'outil de production aura évolué parallèlement.
- d'autre part, c'est l'introduction des nouvelles technologies qui a le plus à pâtir des cycles de développement longs du secteur militaire. Choisir dix ou quinze ans à l'avance la technologie des futurs produits conduit à ne pas tirer profit des évolutions technologiques qui seraient par exemple issues du civil. Cette situation conduit certains audités à ressentir un manque d'études en amont pour anticiper au mieux les choix technologiques et/ou de liens entre études en amont et programmes.

4.5 Conséquences des faibles quantités

Les unités de fabrications travaillant dans les Centres de Fabrication de SAGEM *SA* pour les produits de la défense sont confrontées à l'organisation de productions caractérisées par des quantités faibles, souvent remises en cause et des ruptures de cadence.

Il est du ressort de l'industriel de mettre en place la meilleure organisation pour traiter ce type de production, en recherchant malgré tout le maximum de synergies avec les productions civiles.

Cependant, la prise de conscience des conséquences sur les coûts de ces remises en cause de quantités et ruptures de cadence doit notamment motiver nos clients dans :

- la fiabilité des prévisions (qui devraient d'ailleurs s'améliorer dans la mesure où l'on travaille dans un contexte de coût objectif),
- la prise en compte des points durs exprimés dans le « contexte de l'expression du besoin » ; expression du besoin prenant en compte les possibilités d'export, les applications multiples dans les différentes armes et les produits existants.

4.6 Méthodes

Il s'agit là d'un domaine qui concerne plus les habitudes de travail des bureaux d'études concernés par les programmes de Défense que les points durs associés aux exigences des Services Techniques dans la mesure où ces exigences auraient été par hypothèse réduites au strict nécessaire.

Comparativement avec les activités du domaine civil, et bien que SAGEM *SA* se soit très tôt préoccupé de synergies entre ses différents secteurs d'activité, les exigences spécifiques du secteur militaire ont historiquement conduit les bureaux d'études concernés à adopter des méthodes, à configurer leurs outils, et à se constituer des bases de données spécifiques.

Ceci est particulièrement vrai pour tout ce qui concerne les composants et les coûts associés.

Le recours à la sous-traitance n'est pas toujours envisagé ni suffisamment orienté vers les coûts.

5. LES PROPOSITIONS DE NOUVELLES FAÇONS DE PROCEDER

5.1 Propositions issues de la comparaison avec les secteurs civils

Un grand nombre de points durs ont été identifiés par comparaison avec les façons de procéder des secteurs civils. En prolongeant cette comparaison, on en déduit donc les suggestions associées :

- obligation de résultat, pas de moyens,
- forfaitiser au maximum les prestations,
- revoir le rôle de la surveillance étatique auprès des industriels,
- ne pas démarrer de production sans qualification complète,
- renforcer le « marketing achat » chez nos clients étatiques,
- pratiquer l'appel à la critique des cahiers des charges et l'appel aux propositions d'optimisation,
- demander dans les réponses aux appels d'offre un paragraphe concernant la CCO (Conception à Coût Objectif).
- effort d'industrialisation progressif.

5.2 Propositions visant à compenser les spécificités des marchés militaires

Ces spécificités sont liées au contexte organisationnel, à l'étroitesse du marché et donc quelquefois à un manque de concurrence :

- mise en place d'équipes intégrées Services Techniques/ Opérationnels,
- pousser et choisir en priorité des architectures faisant appel à des sous-systèmes,
- pratiquer l'achat de licences pour les produits logiciel,
- demander dans les réponses à appel d'offre les informations concernant le taux de réutilisation et le taux de réutilisabilité de ce qui aura été développé,
- pratiquer dans certains cas la démarche courte d'approvisionnement
- définition du besoin sous forme fonctionnelle.

5.3 Propositions visant à intégrer rapidement les nouvelles technologies

- demander dans les réponses aux appels d'offre un chapitre concernant l'évolution future du produit,
- pratiquer régulièrement des réunions d'« avance de phase » avec les industriels,
- atteindre des prévisions plus fiables en matière de quantités et de délais,
- identifier les chemins critiques dans les Programmes d'Armement pour mieux cadrer les développements,
- figer les choix technologiques le plus tard possible.
- encourager les conceptions fonctionnelles faisant appel au maquettage virtuel,
- notion d'année modèle : pas de gestion de configuration par le client final.

6. CONCLUSION

Les points durs dégagés et les propositions déduites pour faire évoluer les façons de procéder touchent principalement aux conditions dans lesquelles les industriels sont amenés à travailler avec les services officiels du secteur de la Défense ou avec les maîtres d'oeuvre de ce secteur.

Pour que ces propositions trouvent toute leur efficacité, elles doivent aussi rencontrer un contexte favorable dans les entreprises elles-mêmes. Le groupe de travail qui s'est chargé de l'analyse exposée ci-dessus en a également dégager les facteurs principaux :

- cohabitation de fabrications militaires et civiles,
- mobilité des personnels entre les différents secteurs,
- valorisation et renforcement horizontal des métiers de base à travers les différentes activités,
- présence sur le marché international avec des parts de marché significatives,
- saturation des moyens de production.

Cost Management Processes for Satellite Communications Systems: Lessons Learned

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SUMMARY

A satellite is a spacecraft bus and an integrated payload designed to perform a mission in space. Satellite systems encompass assigned orbital slots, launch support services, a space control segment, and terrestrial communication links for an end-user. Value added data-to-information regimen to fulfill customer demands for specified services is the objective. Satellites are not considered separately from these other segments but complementary to the system.

Hughes Space and Communications (HSC) cost-management experience focuses on the satellite because we develop and manufacture satellite systems for domestic and international customers. Currently, 64 Hughes-built commercial satellites are in service in the United States and around the world, with a spacecraft reliability record of better than 99%.

We also purchase blocks of launch services from the international launch vehicle community and either own or lease tracking, telemetry, and commanding services and provide technical support for customer operations. These require long-lead procurement to manage cost effectively and to pass these savings on to our government and commercial customers. Cost, schedule, technical performance, and customer focus are the key factors that shape our integrated management strategy with respect to cost management. These are essential to secure and assure our continued success as a viable business.

In the United States, government, aerospace, industry, and academia have teamed to sponsor a "lean aerospace manufacturing initiative." The strategy is lean because it does more with less—often much less. It cuts cost and reduces cycle time while improving productivity and quality. The lean aerospace manufacturing industry initiative, with emphasis on the end customer, value streams, customer-forward manufacturing and assembly, leading-edge technology insertion, and quality assurance is exceeding performance projections and reducing mission life cycle costs [1]. Similarly, our cost and management process has significantly increased employee productivity by 47% and reduced costs and cycle times by 30% and is widely emulated within the satellite industry.

Therefore, the emphasis of this paper is on the satellite manufacturing enterprise, reduced cycle times, and the changes in business practices and processes needed to satisfy the customers' contractual demands.

1. INTRODUCTION

The onset of a global information age with cost-effective and more efficient communication information sharing will contribute to the industrial world's productivity and economic growth into the foreseeable future. In this increasingly borderless world, developing countries will experience this too.

From an international security perspective, space systems provide vital support to the NATO Command, Control, and Information System. Satellite communications already form a significant component of such systems. Space systems utility was thoroughly explored at the AGARD Mission Systems Symposium, Cannes, France, in 1996 [2].

In this context, demand for satellites is increasing, particularly in the telecommunications sector. Cost reduction in the satellite manufacturing industry is encouraging demand. A global telecommunications paradigm shift in business affairs with concurrent advanced technology investment in space and terrestrial systems propels this revolution. In the future, new constellations of potentially interactive communications satellites will fly in low earth, medium earth, and geosynchronous earth orbits (Figure 1).

In addition to commercial market imperatives, U.S. government acquisition reform is spurring this process and is encouraging the satellite industry to make further gains in cost management as well. Efficient and cost-effective operations are key if HSC is to remain in business, grow and prosper, and contribute to the progress of international businesses.

More recently, progress has also been made in the international regulatory arena where the World Trade Organization and the International Telecommunications Union, as well as individual foreign governments, have taken incremental yet significant measures to help the communications satellite industry capitalize on its investment, realize its global potential, and lower the cost to users.

The space industry is driven by a number of significant external affairs that impact our ability to meet demand but which, in fact, may be cost drivers that are difficult to mitigate. These external factors include international government regulations and standards; acquisition policy, processes, and reform; the rapid pace of space technology development; and socio-economic changes to the aspirations of people in the global village. While these changes are not entirely within the control of the satellite industry, it is necessary to understand them.

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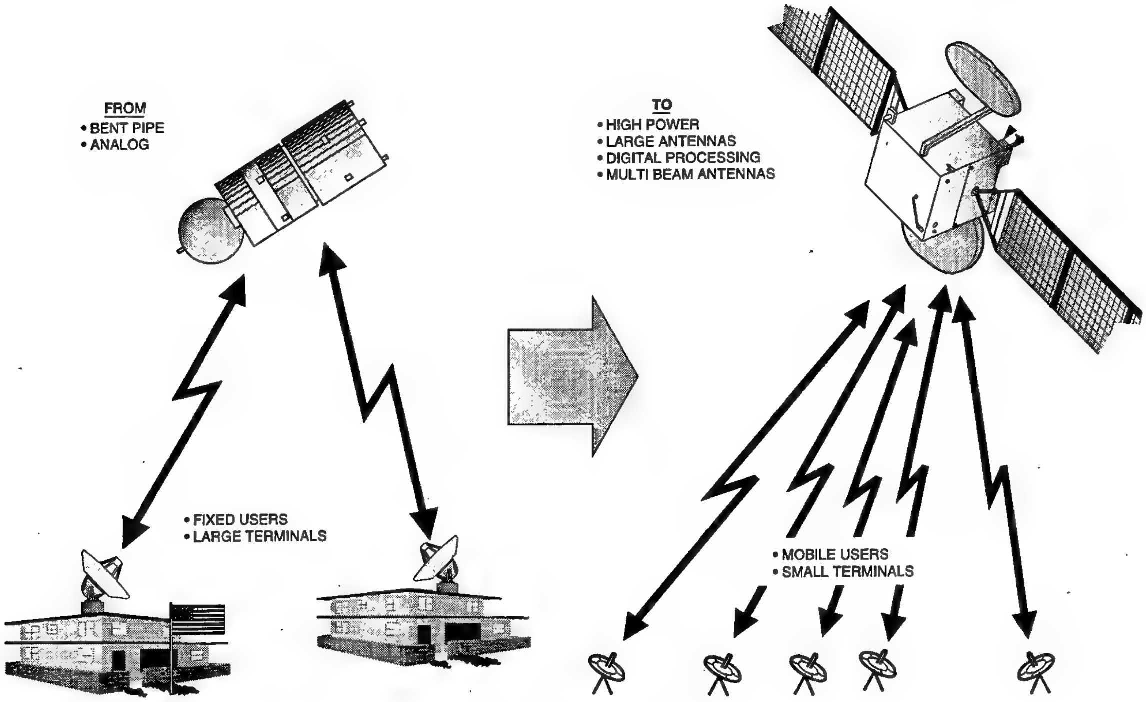

Figure 1. Satellite Trends

The end of the Cold War caused declining defense budgets for NATO countries in general and the United States in particular. The overall U.S. defense budget decreased from a peak of $390 billion in 1985 (constant FY 97 dollars) to $250 billion in 1997, a reduction of 35.4% [3]. The U.S. space budget, in contrast, has remained nearly constant and may slowly increase as the next generation of military satellite communication systems and other mission areas are addressed. As a result, the U.S. aerospace industry consolidated with acquisitions and mergers that resulted in a significant decline in excess capacity. Concurrently, its space systems arm now embraces cost-effective satellite manufacturing techniques in a strategic response to demand.

2. INTEGRATED GOVERNMENT AND COMMERCIAL SATELLITE MANUFACTURING

Cost visibility is an area where HSC is seeking common government/commercial processes. Since HSC manufactures both government and commercial spacecraft and payloads under one roof, we need to achieve process commonality in one important aspect of cost visibility—earned value management.

HSC has a validated system that complies with the cost/schedule control systems criteria for government cost-type contracts to measure earned value. We also use earned value measurement to track progress on commercial programs and government fixed-price contracts. Because specific procedures for implementing earned value across our programs vary significantly, we formed a multifunctional team to facilitate standardization of earned value management. This earned value performance measurement process may be used by any program to generate real-time, verifiable data in a consistent format that provides an integrated status of cost, schedule, and technical process.

A key to the successful implementation of a common earned value management system is adoption of commercial earned value approaches to provide an effective early warning management tool. These proven processes include emphasizing upfront technical planning and scheduling as opposed to cost and schedule monitoring; producing internal status reports more frequently with much less detail; organizing and reporting data in a manner that mirrors how HSC manufactures; reporting variance analysis on critical items only as opposed to reporting on all variances; focusing on adherence to technical and schedule goals before costs (the philosophy being that focusing on key technical accomplishments per the planned schedule will cause planned costs to fall in line); tracking costs (i.e., dollars) at higher levels to the program work breakdown structure; and using computer technology to provide real-time, on-line access to performance data.

Our efforts to develop a common earned value management system for all of our commercial and government programs emphasize commercial "best practices." Use of such practices results in a streamlined approach that may be used by all company managers to get real-time progress information in formats consistent with how they manage. This type of system serves the needs of program managers to have an effective real-time management tool.

3. RISK MANAGEMENT

Effective risk management, essential to cost control, has two major components—standardization and the integrated product team approach for risk identification and mitigation. Standardization of products and processes reduces variability and leads to more reliable systems. Integrated product teams help ensure that all risk areas are identified and that the customer and contractor work together to mitigate them.

Commercial space companies have moved to product design standardization. These adaptive, modular product line designs serve both government and commercial customer needs. With our highly successful HS 376, HS 601, and the new HS 702 satellites, HSC has reduced cost, cycle time, and variability by using proven, stable designs and heritage components, and has realized significant manufacturing cost savings.

Along with standardizing design, the industry is also standardizing processes. Costs and cycle time are reduced even further, and quality is improved by minimizing out-of-sequence work and unnecessary rework. Through process standardization, potential risks are identified and assessed early and continuously throughout the product life cycle. Using this tool, management can apply mitigating strategies early.

Commercial customers work with the satellite industry to manage overall risk to their business plans. They, too, seek to reduce their risk: risk to cost, schedule, launch, or on-orbit performance.

Customers reduce cost risk by negotiating fixed-price contracts. They reduce launch or schedule risks in three ways. First, they provide financial incentives for on-time delivery. Second, they take out launch insurance or arrange for on-orbit delivery. Third, they reduce their launch risk even further by purchasing a relaunch capability. They procure long-lead items and subassemblies to ensure that they can launch an equivalent spacecraft within a short period of time, typically one year, in the event of a launch failure.

Performance risk is managed by providing financial incentives to contractors for performance on orbit. Customers may further reduce on-orbit performance risk by purchasing backup spacecraft stored either on orbit or on the ground. In emergency situations, they even lease services from another provider.

The key to using these risk reduction techniques successfully is to create a supportive customer-contractor relationship. This is where the integrated product team (IPT) comes in. Using the team approach, both customer's and contractor's perceived risks are identified early. The IPT assesses the issues and agreed-upon priorities. The united resources of all parties focus on solving the highest priority problems first. Significant decision points are agreed upon in advance and executed quickly. This value-added approach leaves routine issues to be resolved by the individual parties.

4. HSC'S APPROACH TO THE COST MANAGEMENT PROCESS

HSC generally has held 50 to 60% of the geosynchronous commercial market since the 1970's. The market share in 1985 was 50%; 1990 showed an increase to 67%, and 62% at the end of 1996. In addition to new technology, HSC has continued to emphasize cost, schedule, and quality. To sustain this rate of market share and improve, production facilities were consolidated into an integrated satellite factory (ISF). Operations from many facilities were integrated into the ISF where production and integrated satellite testing for the spacecraft and payloads take place.

Yet, more improvement had to be made, and HSC, like the rest of the satellite industry, began re-examining its external business relations, which ultimately led to a streamlined manufacturing process with a cost-management (CM) integrated management approach at its heart (Figure 2). CM promotes the use of generic, standard processes through individual product design. In short, CM is focused on lowering structural costs and providing more manageable and predictable processes. CM relies on the tools of Process Management (Process Improvement, Benchmarking, and Business Process Reengineering) derived from an innovative self-improvement initiative which has transformed our operations.

5. HSC'S ARCHITECTURE ENGINEERING TEAM

In January 1995, an architecture engineering team (AET) began its Phase A by re-examining our market, customers, and business goals. External data gathering with customers and suppliers helped us ascertain what our customers need to sell their products and services. Teams were dispatched to interview customers about their market trends and future needs and what they will need from us, capabilities, behavior, relationships, costs, and responsiveness. Similarly, teams interviewed our suppliers about their expectations of a preferred customer.

HSC used the resultant information to determine its building blocks for the future. Key processes were identified, and a focus team for each key process was formed. These teams used CM as the fundamental departure point. CM became a tool by which to achieve profitability via maximization of asset utilization while meeting the customers' needs. Asset utilization, in turn, was maximized through setting target costs for each product line and then using the tools of process and materiel management to achieve these target costs. A cost management process team is supporting the AET initiative for cost management process redesign. Three basic principles apply:

1. Every process must be aimed at meeting the needs of the customer.
2. The organization as a whole is a process.
3. Processes need to be standardized, i.e., common.

Executive leadership regularly monitors team progress and removes barriers. Program and line management are responsible for incorporating improvements, which they do by developing plans for each program/organization; integrating

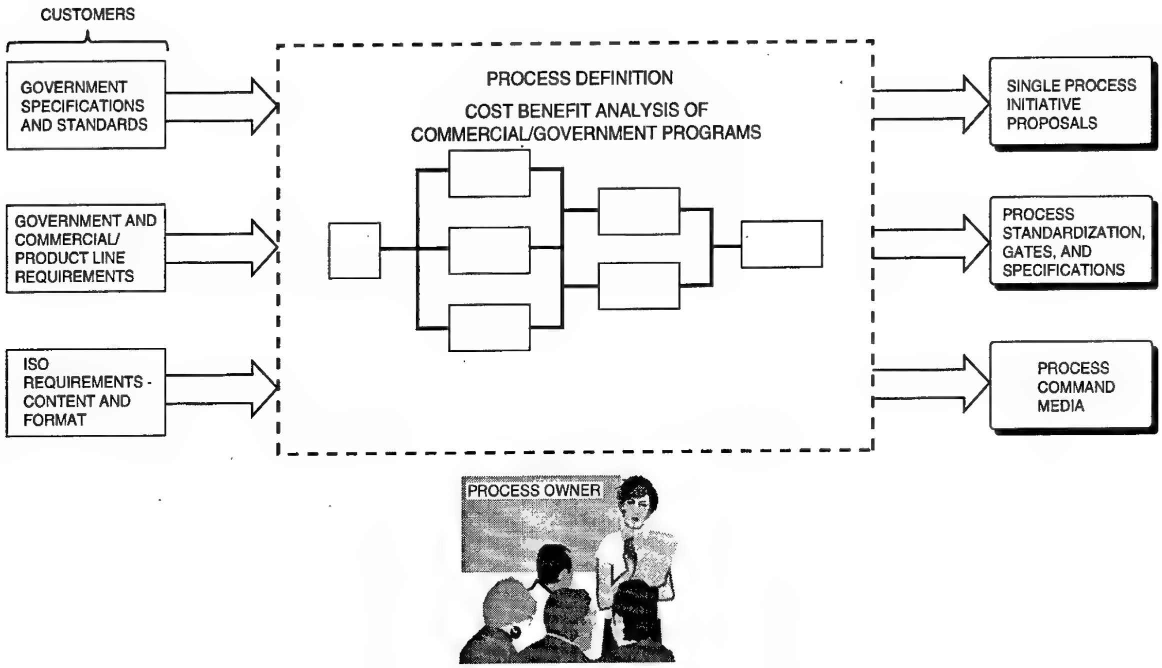

Figure 2. Integrated Management Approach

and implementing them at the enterprise level. Executive tracking of overall metrics ensures incorporation.

Has this approach been effective at HSC? Yes! This approach is the basis of the entire improvement effort that has been ongoing at HSC over the last two years, known as the AET improvement effort. The AET Phase A team submitted the following major thematic recommendations:

1. Become a process-focused organization
2. Implement gated processes
3. Redefine the suppliers/materiel process
4. Develop custom products using standard components in a level factory
5. Place broad emphasis on commonality
6. Implement integrated product development
7. Implement a shared information infrastructure

These themes were then further refined into 14 major building blocks:

1. Lifetime customer relationships
2. Gated, process-focused organization
3. Standards and reuse
4. Level factory
5. Integrated technology plan
6. Product upgrades through gated insertion
7. Custom products using standard building blocks
8. Managed supplier relationships
9. Strategic make/buy decisions
10. Shared information
11. Effective hand-off of requirements
12. Design to cost and schedule
13. IPD/IPT process
14. Product line focus

Over the past 18 months, HSC has begun implementing these building blocks. We have established a new customer partnering, technology development, materiel/supplier partnering, and product delivery processes—culminating in the HSC business operations plan. The basis of this plan is that it recognizes the business as a single, high-level process which, in turn, links and integrates the critical operating processes throughout the corporation. As a result of this process-focused approach toward achieving excellence in customer satisfaction and operating performance, we have

1. Redesigned our customer partnering process to focus not only on initial customer satisfaction and sales, but also on properly "staging" the new work that allows the product delivery to meet the cost and schedule targets established.
2. Aligned our various programs into product lines, each using basically common spacecraft buses, to promote commonality and long-term product evolution.
3. Identified the major, critical operating processes that are required to meet the customer's needs and assigned a process owner to each. The process owner is responsible for the process definition, control, and improvement, regardless of the number of line organizations that participate in that process.
4. Realigned our organizational structure to better support and operate major critical processes.

5. Implemented design-to-cost/schedule as an overall operating methodology with long-term improvement targets established by product line, which have in turn, flowed them to each product delivery and supporting business unit.
6. Established training to instill the concepts and methodologies of trust and teamwork required to operate in an integrated product team environment.

The HSC plan for operations improvement is a broad and deep commitment to fundamentally improve all areas within the company based on continuous measurable improvement using a customer and process focus. The above describes just some of the efforts being undertaken to maintain HSC as the supplier of choice to the space-based telecommunications market. We feel that our efforts are strategically aligned with the cost-management approach.

6. LESSONS LEARNED

Efforts to improve using a process focus have been embraced in an environment that prides itself on technical excellence. Moving in that direction—on how work is really done, and not just the output of that work—required special effort, and we learned quite a few lessons along the way. For example:

1. HSC needed a clear understanding of the problem being addressed.
   - What are the drivers for change?
   - What are the basic problems to be solved?
   - What are the expected outcomes?
2. The executive level needed to be fully aligned on the objectives and methodology to be employed.
   - Do not move past this point until leadership is aligned. The organization will resist.
   - Use internal resources to educate the leadership on the methodology.
3. A business case for new design must be established to justify the projected investment. Sufficient resources must be allocated. The leadership must be dedicated.
4. The team must be a high-performance team with respected, credible members, and it must be allowed time to work the details.
5. External data must be collected. It should include the customer's perspective, the supplier's view, and the best practices.
6. The framework was developed as "building blocks." Guidelines were designed. Capabilities were defined: characteristics, policies, systems (e.g., gated processes, commonality, flexibility, shared databases). This framework development should not be in a vacuum.
   - Use others to define the best practices.
   - Start with a high-level team.
   - Have lower-level teams work specifics.
   - Seek constructive criticism. Credible detractors sometimes have insight others have missed and can provide simple, effective solutions.
   - Tie to real business as soon as possible.
   - Manage like a program—tie to compensation since it is in everyone's best interest.
   - Coordinate everything into one enterprise operations plan.
7. Clear goals needed to be allocated throughout the organization.
   - Tie simple metrics (the fewer, the better) to meaningful work that roll up to top-level objectives. Everyone should have a target number, such as cost, cycle time, error rate, etc.
8. Communication must be constant.
   - Create the need for change and understanding of real goals.
   - Educate those who do not appreciate the reality. It is impossible to overcommunicate.
   - Avoid buzzwords; say what you mean.
   - Utilize enabling systems: information technology, management systems, organization.
9. Progress needed to be monitored.
   - Keep a constant focus on simple but effective metrics.
   - Review progress daily with senior management, but rotate the reviews of specific tasks/plans. Do not review everything every day.

The past ways were done for a reason. Times and necessities change, resulting in new realities. We learn from and try to keep the best wherever possible. This shows that the leadership respects past accomplishments, which significantly helps the detractors stay engaged. The future cannot be created, however, by remaining in the past.

7. APPLICATION OF LESSONS LEARNED

At HSC, assembly of the spacecraft bus and payload is conducted as a separate but parallel flow in the ISF. Payload components are integrated and then tested as a complete unit, while spacecraft components, such as propulsion tanks and wire harnesses, are separately integrated and tested. The major components are then mated and tested as a whole in the high-bay prior to environmental testing. The integrated factory includes concurrent engineering activities to enable many key engineers to be located in the same facility and close to the satellites.

HSC also has reanalyzed its commercial product lines—the HS 376, HS 601, and HS 702—to determine how to maximize commonality between the models to reduce costs. The product line plan strives to minimize changes, while supporting rapid payload recombining to meet customer needs. Both commercial and government spacecraft are built in the ISF. The commercial side represents about 55% of the company's satellite business.

Reducing Costs and Cycle Times

Maintaining leadership means being the low-cost manufacturer, delivering spacecraft to meet customers' schedules, producing reliable satellites, employing advanced technology, and assuring the availability of launch facilities.

HSC delivered 11 satellites in 1996 and expects to deliver 24 more over the next two years. At present, our backlog is 39 satellites. To meet strong demand and also to lower costs, HSC has made its manufacturing facility more efficient. Since 1992, it has increased productivity by 47%.

These gains have helped HSC reduce cycle time by 30% over five years. Basic models of the HS 376 and HS 601 spacecraft now can be delivered in two years or less. In 1996, to meet customers' tight schedules, HSC delivered two HS 376 satellites within 14 months of being ordered.

Reliability Record/Technology Development

By early 1997, HSC had reached a new milestone: Of the 120 commercial communications spacecraft we have launched in the past 32 years, 64 are still in service. Together, they represent 850 years in operation. Our nearest competitors' fleets each have accumulated only about a third as many years. In addition, more than 80% of the satellites have exceeded mission life by at least 10%.

Hughes also is a spacecraft technology leader. Our continuing investment in technology development is dramatically improving the capabilities of satellite-based communications systems. For example, advanced solar array technology, including new gallium arsenide solar cells developed by a Hughes subsidiary, doubles the power of existing satellites. Another key Hughes technology is a digital processor that will operate as a "switchboard in the sky" for the wireless communications of future satellite-based systems.

Global Launch Commitments

HSC has been delivering satellites for launch at a rate of nearly one a month since late 1993. To increase competitiveness, HSC must be able to offer customers a variety of launch options. HSC has been at the forefront in negotiating advance bookings for multiple launches. These commitments have helped increase competition in the launch industry, which is expected to result in greater availability and reliability, lower costs, and the ability to launch larger satellites.

By early 1997, HSC had secured more than 50 future launch vehicles to be provided by companies in the United States, Japan, Kazakhstan, and elsewhere. The 1997 launch schedule calls for 11 spacecraft to be lifted by rockets at sites in Cape Caraveral, Florida; Kourou, French Guiana; and Baikonur, Kazakhstan. In previous years, Hughes also sent satellites and launch teams to sites in Tanegashima, Japan, and Xichang, China. To ensure that its satellite customers will have launch vehicles available when the satellites are ready, Hughes has entered into a number of long-term agreements with rocket providers in the United States, Russia, Japan, and China.

8. CONCLUSION

Olympic track and field coaches would agree that the shorter the race, the more important the start. Understanding requirements and expectations from the outset is key to success. Cost management moves fast; therefore, leveraging a front-loaded CM process along with clarity of agreement sets the stage for a successful program. When cost is treated as an independent design parameter, the desired business outcome is probable; but without CM, failure is assured because the total CM requirement increases with system complexity; piece part, component, and subsystem indices are not comprehensive enough to measure.

Finally, one must remember the political, economic, and policy realities that sometimes conspire against rational cost management. Our own estimates indicate that regulatory and acquisition requirements may drive the total cost of a satellite in terms of financing, quality assurance, materiel, and engineering. The choices sometimes presented by the external environment are not always conducive to cost-effective decision analysis. Programmatics, acquisition strategies, and requirements all require a sensitivity to and understanding of the effects of policy mandates because what will be in space in the next millennium is in the pipeline today.

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The Boeing 777: A Look Back

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ABSTRACT
The Boeing 777 is the largest twin-engine commercial jet transport in service today. In 1990, approval to proceed with its development was contingent on defining an airplane the airlines would buy at a price Boeing could afford. Innovative processes were developed and implemented that focused on achieving customer preference and reduced program cost. These processes centered on Design Build Teams, Digital Product Definition, and Digital Preassembly. Two years after delivery of the first airplane, the data show that the processes made the 777 the preferred airplane, lowered program costs as predicted, and set new standards and expectations for the development of jet transport aircraft.

Figure 1. 777 First Flight

INTRODUCTION

The Model 777 (figure 1) is the newest member of the Boeing family of airplanes, filling the gap between the Model 767 and 747.

It can carry from 300 to 550 passengers over distances up to 7,500 nmi, depending on configuration selected, at speeds of 330 kn/ 0.84 mach. Its state-of-the-art features and technology, its award-winning interior design, and its inservice performance since first delivery in May 1995 have earned it praise and recognition from the technical community, airlines, and passengers alike.

Its most significant feature, however, is the totally new way the airplane was developed using digital technology and a "working together" philosophy to meet customer requirements at a reduced cost. This paper takes a look back at the design, the development challenge, the processes used, and how the airplane and those processes are perceived 2 years after initial delivery.

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

THE PREFERRED AIRPLANE

The Model 777 was conceived with the strong help of our airline customers. Eight airlines in particular, from Europe, Southeast Asia, and the United States, worked with Boeing to configure an airplane they preferred.

The result is the largest twin-engine airplane available (figure 2). It is offered as a family of airplanes with takeoff gross weights ranging from 506,000 lb to 660,000 lb in three configurations: 777-200, -200IGW, and -300, with additional growth versions under study (figure 3). The 777 is offered with a choice of engines from three manufacturers at various thrust ratings (74,000 lb to 98,000 lb thrust) depending on the requirements of the customers.

The latest materials technology is used for improved structural durability, maintainability, and inspectability, while providing a lightweight and cost-effective design.

An all-new circular fuselage cross-section offers greater flexibility in cabin arrangement and cargo carrying capability. The passenger cabin provides an open and spacious interior with a high level of seating versatility, ranging from six abreast in first class to seven or eight abreast in business class and nine or ten abreast in economy class. Lavatory and galley complexes are movable within flexibility zones to permit the airline to reconfigure the interior with minimal downtime and cost. The forward and aft cargo compartments provide 5,056 ft^3 of cargo space for both ULD containers or pallets, with 600 ft^3 capacity in a bulk cargo compartment.

Airplane systems are based on proven designs with advanced technology features added on the basis of enhanced performance, reliability, and economy.

The flight deck is designed with extensive human factors and industrial design influence to enhance pilot comfort and reduce fatigue, especially important on long-haul flights. Six large LCD displays provide flight control, navigation, engine and alerting information with improved visibility, readability, and reliability at reduced space, weight, power, and heat. New functionality is provided for display management, data communication, and electronic checklist to allow the crew to operate the airplane more efficiently.

Fly-by-wire flight controls are provided for primary, secondary, and high-lift control surfaces. The design maintains conventional control characteristics and controllers to retain existing pilot cues, with selected enhancement functions added to reduce workload.

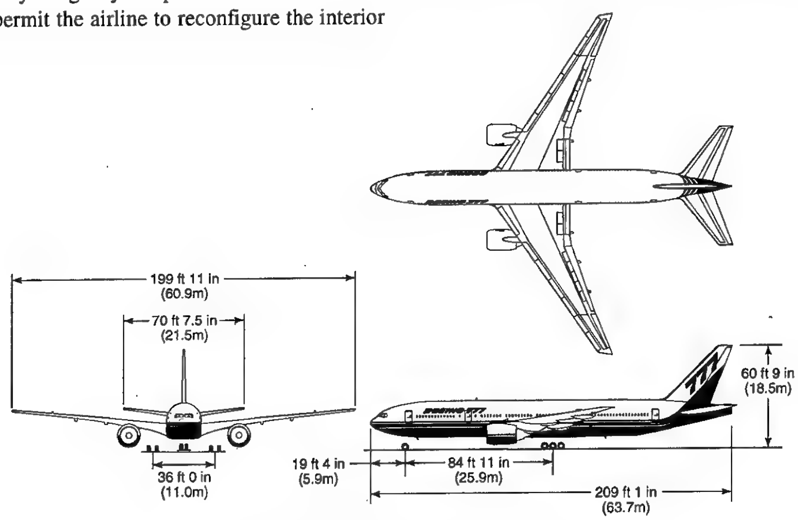


Figure 2. 777 General Arrangement

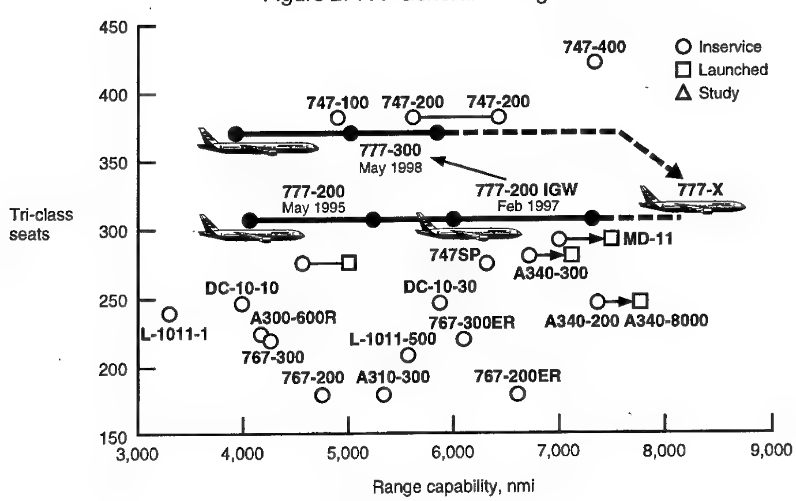


Figure 3. Family Plan

The 777 avionics include the first use of an integrated, modular avionics concept on a commercial transport. Functionality for primary displays, flight management, thrust management, control maintenance, data communication, airplane condition monitoring, and flight data recording is implemented in two avionics cabinets each with eight line replaceable modules. The four input/output modules and four core processor modules use a common hardware and software architecture. This implementation results in reduced weight and power consumption with increased reliability, simplified system interfaces, and improved fault isolation compared to federated systems. A new multitransmitter data bus (ARINC 629) permits increased communication between all systems, resulting in improved functionality, reliability, cost, and weight. Software is onboard loadable to reduce spares costs and permit faster incorporation of functionality improvements.

The electrical power system provides increased redundancy (three main generators, two backup generators, one standby ram air turbine-driven generator, four permanent magnet generators) to satisfy fly-by-wire and ETOPS requirements.

The onboard centralized maintenance system is designed with the needs of the line mechanic in mind to facilitate rapid problem resolution and return to service. Reliable, redundant systems, combined with the functionality and extensive coverage of the maintenance system, ensure our customers high airplane availability for revenue service.

THE 777 DEVELOPMENT CHALLENGE

In 1990, the Boeing challenge was how to develop an airplane that was preferred by our customers at a price they were willing to pay and we could afford to build. Key attributes included:

1. An airplane preferred over the competition because of superior functionality, reliability, maintainability, and economics.
2. Reduced overall costs, based on a 300-airplane program.
3. Service ready at delivery.

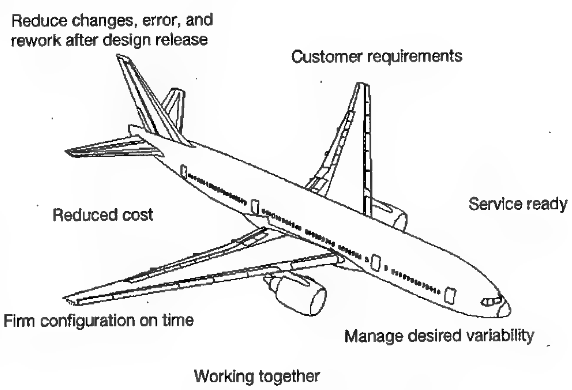


Figure 4. 777 Development Challenge

A review of past programs identified the major challenges that needed to be addressed to make the program a success (figure 4). Most fundamentally, we needed to determine what the customer wanted. This was definitely not an easy task, since requirements from multiple airlines can be quite diverse and even contradictory.

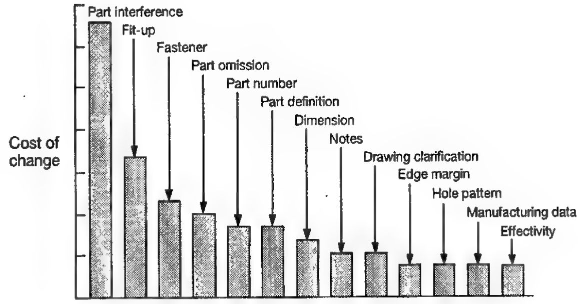


Figure 5. Traditional Cost Drivers

Change, error, and rework needed to be reduced, to reduce cost. Data showed that part interferences and fitup problems in the factory were major reasons for engineering change (figure 5). Since the cost of change increases significantly, the later the change is implemented, major cost savings would be achieved by reducing change, error, and rework after design release.

We would need to deliver a service-ready, reliable airplane on the day promised, without benefit of a prototype program. Our customers were tired of finishing the airplane development in revenue service and would only purchase an airplane that worked. Furthermore, to market the airplane successfully against three- and four-engined airplanes, the 777 needed to meet stringent reliability requirements for 180-min ETOPS (extended-range, twin-engine operations) at entry into service. This would be an industry first, since past models required 2 years of inservice experience to obtain ETOPS approval.

We would need to communicate more effectively among 4,500 engineers, 200 suppliers and 6,500 manufacturing employees. This communication would be vital to reduce change, error, and rework due to late or incomplete design information.

This resulted in a program development plan (figure 6) that focused on the following:

- Involving the customer to define the preferred airplane.
- Ensuring that all parts are designed to work and fit together before release, for 50% reduction in change, error, and rework.
- Working together to share facts and data and resolve issues.

These goals were implemented by "preferred processes" that were at the heart of the 777 Program:

- Design/Build Teams.
- Digital Production Definition.
- Concurrent Product Definition.
- Digital Preassembly.
- Enhanced Validation.

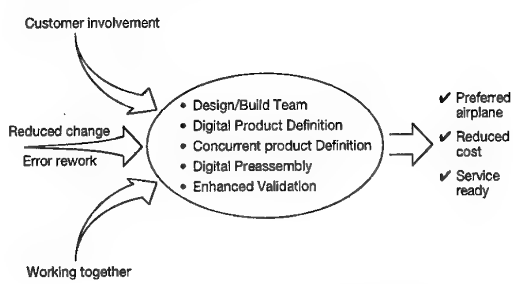


Figure 6. 777 Development Plan

DESIGN/BUILD TEAMS (DBT)

Development of a jet transport is a large and complex task involving many organizations in many locations. This largeness and complexity create their own set of problems. Activities tend to be conducted in series with results "thrown over the fence"; communication is incomplete with not all facts and data available for consideration; interorganizational rivalries and misunderstandings arise and take priority over what is best for the product.

This is further aggravated by increasing product complexity and job specialization, which result in no single person understanding all aspects of the development task. In addition, time intervals of up to 15 years between new programs makes the experience of the development team a key concern.

The 777 program countered these problems with a process of working together in design/build teams. Each team comprised Engineering (Product Definition), Manufacturing (Plans, Tools, Fabrication, Assembly), Materiel (Outplant Production Procurement), Customer Services (Training, Spares, Maintenance Engineering, Field Service Engineering), Quality Assurance (Plans, Inspections, Records) and Finance (Design to Cost) and often included supplier and airline representatives. This ensured that all facts and data with respect to functionality, producibility, maintainability, affordability, and customer preference were available for the best possible decision prior to design release. This process, implemented by program direction and extensive training and continuously reinforced, encompassed Boeing, its suppliers, and customer airliners.

Each DBT was the primary organizational entity and was responsible for the parts, plans, and tools definition of one area of the airplane. The teams were organized along traditional engineering functional lines, with members assigned to the team by their home organizations (figure 7). Each team was co-led by Engineering and Manufacturing. Higher level integration DBTs for each function ensured functional integration across the airplane, aided by integrated schedules and integrated work statements. An independent Zone Management organization was used to validate cross-functional airplane-level spatial integration (figure 8).

Full-time team members were collocated to facilitate communication. Regular DBT meetings were held with all members present to review progress to the plan and resolve any issues or concerns. At the peak of the design effort, 238 DBTs existed.

When the program shifted to the build phase, Manufacturing Integration Teams (MIT) were formed in addition to the DBTs to resolve manufacturing issues.

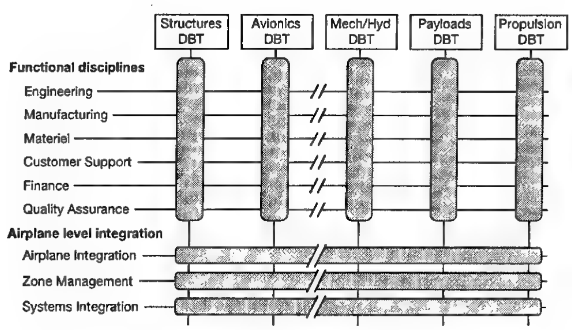


Figure 7. 777 Design/Build Team

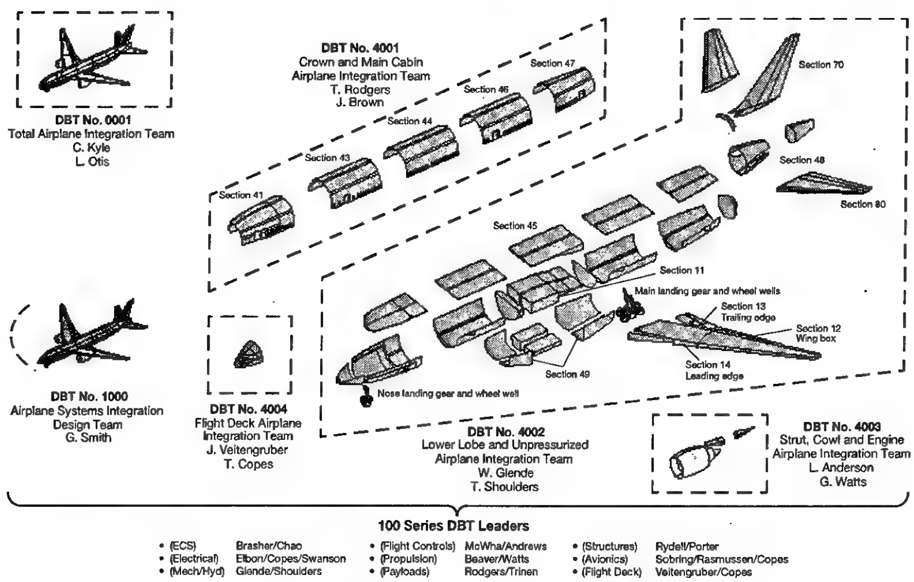


Figure 8. 777 Airplane Integration

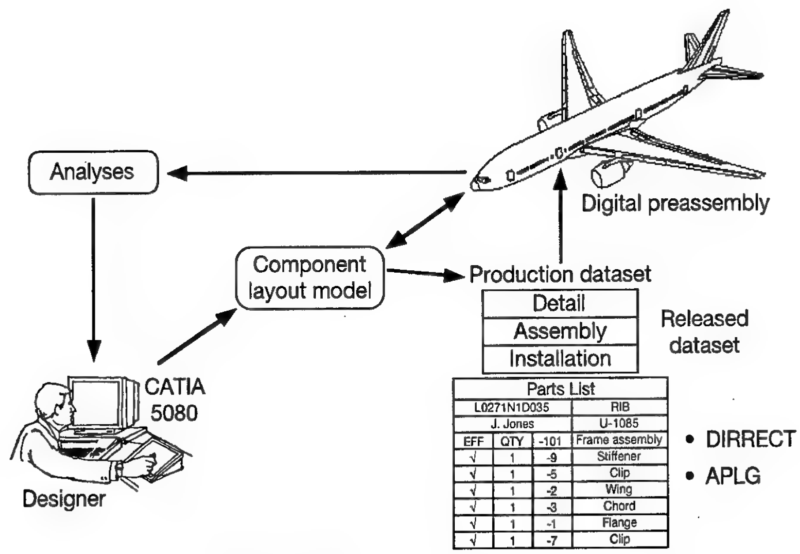


Figure 9. Digital Production Definition (DPD)

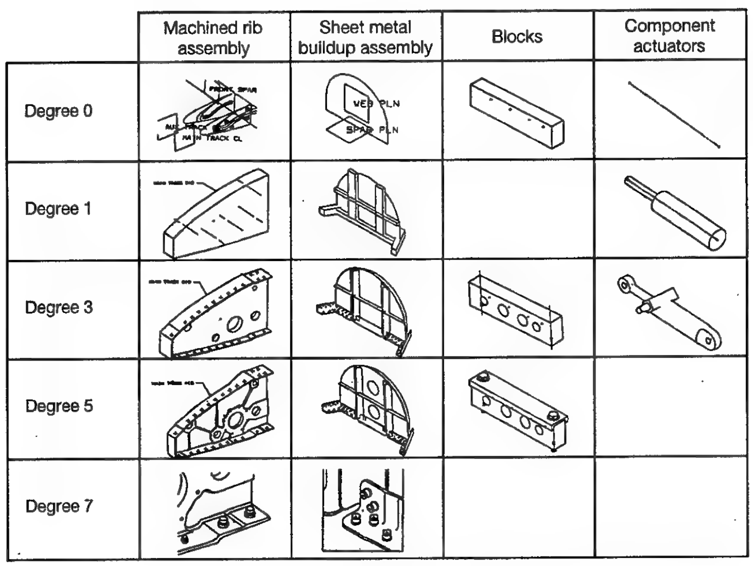


Figure 10. Digital Preassembly (DPA)

DIGITAL PRODUCT DEFINITION (DPD)

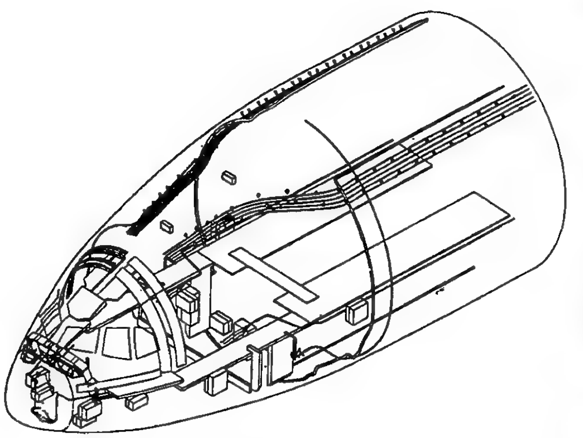
A key benefit of digital product definition is the ability to electronically assemble and analyze the airplane, thereby allowing earliest identification of interference, separation, or access problems. Additional benefits arise from the enhanced data usage by other organizations such as Stress, Weights, Tool Design, or Training. The program standardized on CATIA (Computer-Aided Three-Dimensional Interactive Application) from Dassault Systems, using approximately 2,200 individual workstations linked to eight mainframe computers in the Seattle area. This mainframe cluster also linked to installations in Japan, Wichita, and Philadelphia.

The design process (figure 9) required the engineer to develop his design in a working file on CATIA. Starting with preliminary layout models in airplane coordinates, the design was continuously shared with the 777 Team for digital preassembly. The fidelity of solid-model development (figure 10) increased with time, starting with simple envelope models (degree 1) and ending with a manufacturing-quality model (degree 5). The layouts evolved into individual details, assemblies, and installations that were released to manufacturing. Each digital release included a 3D solid model, 2D drawing data, and a bill of material, in addition to specific manufacturing requirements such as flat patterns or wire frame models. Approximately 90,000 datasets were released.

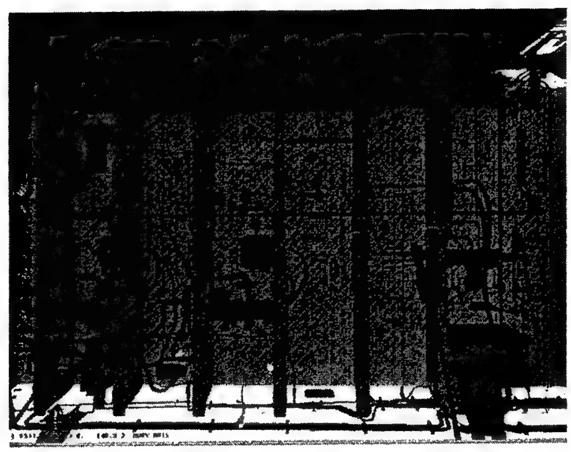
The single source of (digital) Product Definition was used by the various DBT organizations to ensure that the design satisfied their specific requirements. Manufacturing processes used the data in the area of assembly sequence planning, tool design, and production illustration development, as well as numerical control machine tool programming. Customer Services benefited in the preparation of maintenance documentation, ground support equipment design, and training aides.

DIGITAL PREASSEMBLY (DPA)

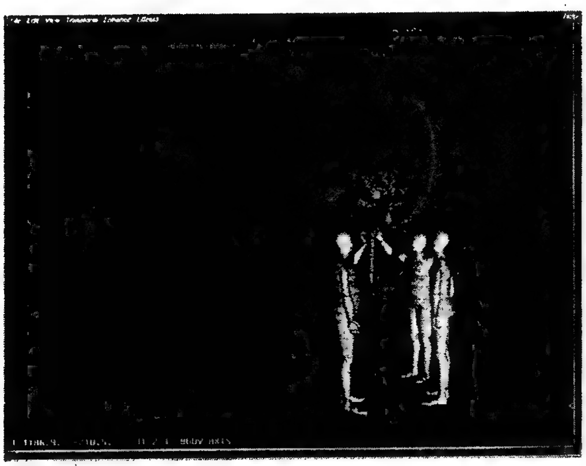
DPA consists of assembling the digitally defined parts into an airplane in order to verify proper design before release. This process eliminated the need for a physical mockup, yet allowed frequent and early design verification. Parts were assembled as needed by designers, analysts, planners, or tool designers, showing the complete airplane volume or only the parts of interest (figure 11). The designer was responsible for frequent sharing of the model, as well as conducting interference checks and incorporating design feedback from other organizations. DPA used two dedicated organizations to manage the digital preassembly. DPA administration provided data management of the share models to facilitate easy access, while Zone Management ensured cross-functional integration of the design through independent design reviews. Integration reviews were held frequently, with five formal reviews during the 2-year design phase. The reviews consisted of a cross-functional review of a particular airplane volume and were chaired by the Zone Management organization. Reviews covered functionality, producibility, and maintainability, including interference checks, interface coordination, and installation/removal access.



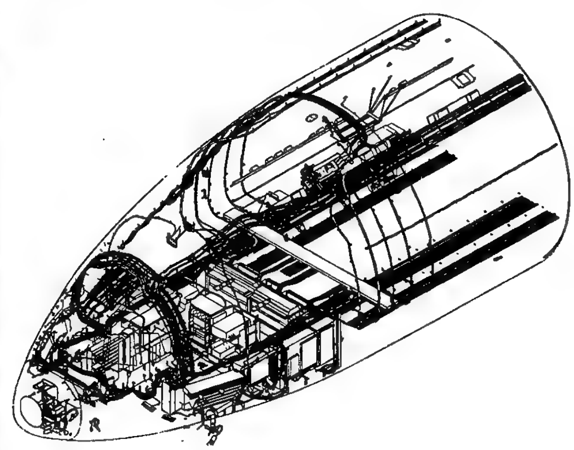
Stage 2
Section 41—Wires/electrical



Fly-Thru software
CATIA image



Full-motion human modeling
CATIA image



Stage 4
Section 41—Electrical

Figure 11. 777 Digital Preassembly

CONCURRENT PRODUCT DEFINITION (CPD)

The purpose of CPD is to define complete and integrated designs, manufacturing plans, and tools prior to release of any product definition, in order to lower the cost of manufacturing and support. This required a strong team sharing information and working together to define the product, including simultaneous design of structures and systems, analyses to support the design, production plans definition, design of critical tooling, and ground support equipment and technical publications development (figure 12). Because these activities were highly interdependent, integrated work statements and integrated schedules were used to coordinate the various tasks. This planning and scheduling activity was facilitated by dividing the program into stages (figure 13), with program and DBT goals defined for each stage.

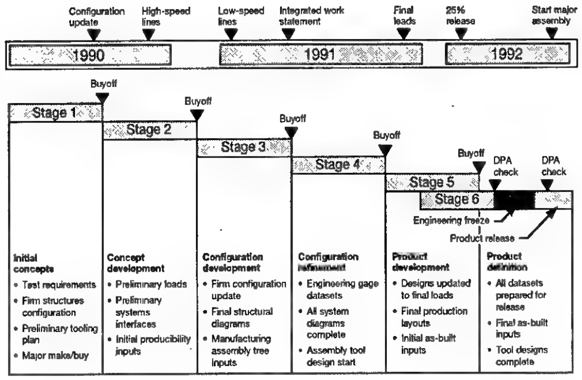


Figure 13. 777 Design Stages

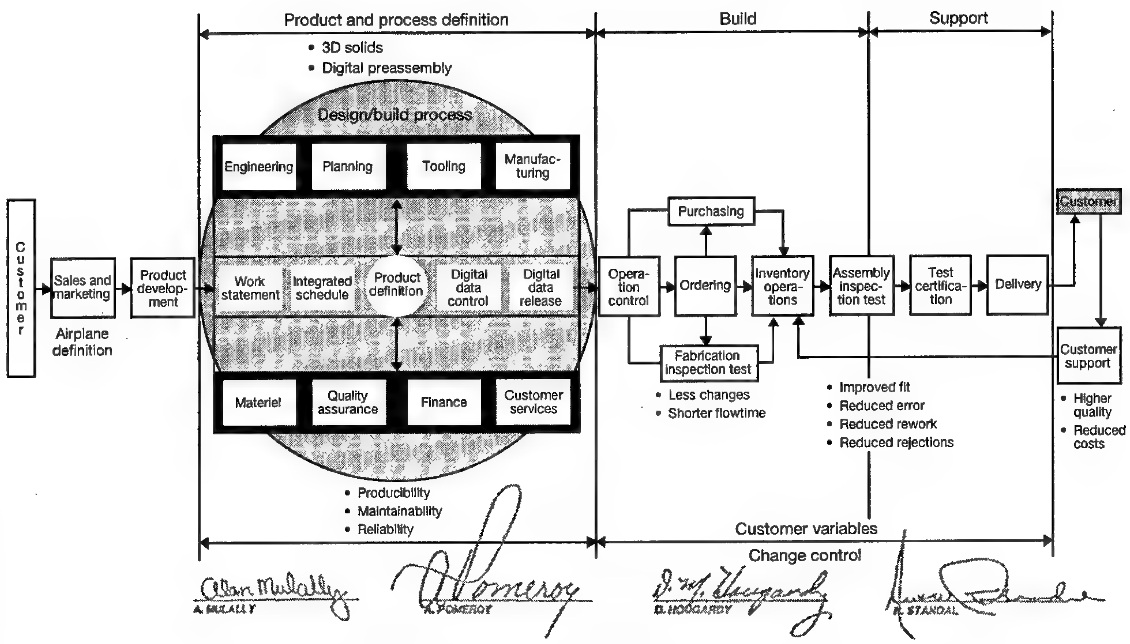


Figure 12. Concurrent Product Definition—Preferred Business Process

ENHANCED VALIDATION

A key requirement for the 777 was to be service ready at delivery, or in our customer's words, "Everything works." This resulted in an enhanced validation program compared to previous models (figure 14).

Early on, an extensive "lessons learned" activity was conducted. Service history was examined to identify existing problems and their root cause; design solutions were then identified to ensure no repeat of the problem on the 777.

Verification and validation analyses were greatly expanded to minimize problems during the lab and flight test phases (figure 14). Digital interface reviews were conducted for each LRU and its member systems to ensure that data and logic flows were understood for all flight phases and operating states. Airplane-level analyses ensured that each function, such as stall warning, was correctly implemented by all subsystems under all operating scenarios as well as normal and failure conditions. Flight deck message reviews were held to ensure that we had implemented the minimum number of messages and that those messages worked correctly. Airplane-level failure analyses went beyond the normal single-system analyses by examining the total airplane effect of single and multiple failures. Operational analyses were led by the pilot community to validate all normal and non-normal procedures.

Lab testing was expanded for both qualification and validation. Equipment qualification testing included "test to failure" conditions to identify and fix weak points in the design. In addition to the standalone and system test facilities, a systems integration lab was used to test the electronic systems. The lab was configured to spatially represent the airplane and used production power generators, wire bundles, electronics, and flight deck components. Simulation of airplane dynamics, environmental conditions, and mechanical systems allowed realistic testing by flight test pilots who performed each test as an actual flight (figure 15).

APU and engines were each subjected to a 3,000-cycle ground test to demonstrate their service readiness, in addition to the normal development and certification tests.

Structural tests included a full-scale static load test and a structural fatigue test. The static load test vehicle was used to demonstrate limit load capability and then tested to wing destruction to determine available margins for growth. The fatigue test vehicle is being tested to three life times, completing a typical flight profile approximately every 4 min, 24 hr a day.

The flight test program used a five-airplane test fleet to validate the design. With first flight in June 1994, development testing had to be essentially complete by November 1994 to support the beginning of a special 1,000-cycle validation program. This test was in support of ETOPS certification and operated the airplane in simulated revenue service (figure 16). A key requirement was that the airplane had to be in production configuration and test results would determine ETOPS approval.

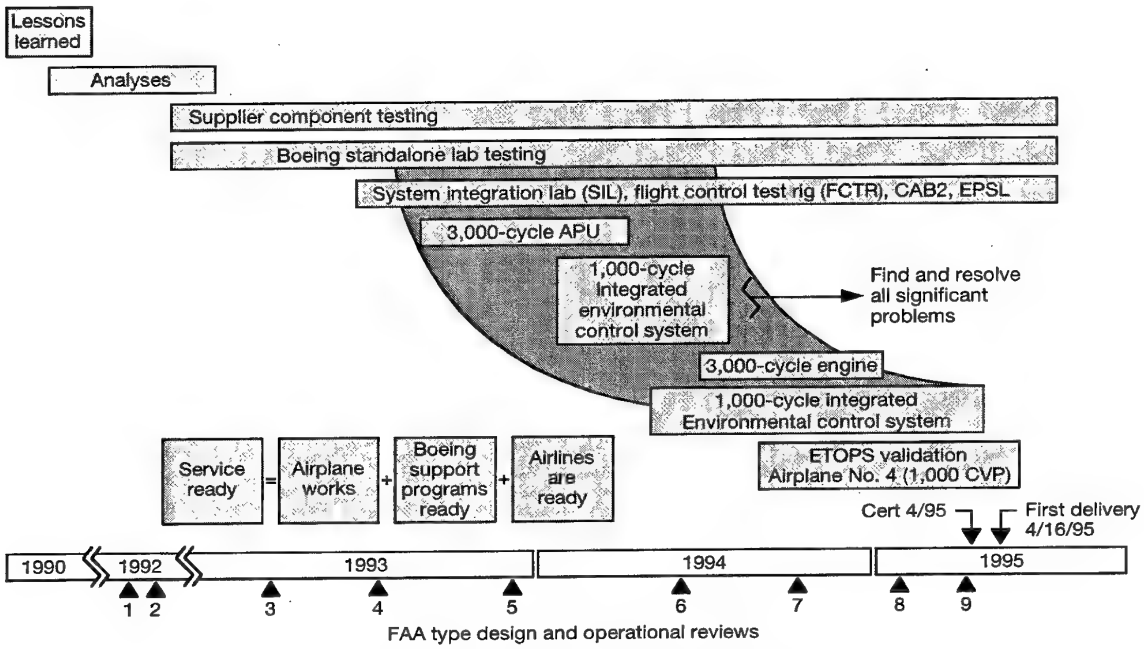


Figure 14. Service-Ready and ETOPS Certification

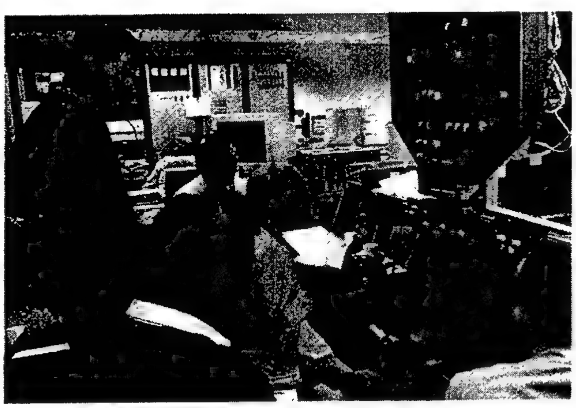


Figure 15. Systems Integration Lab

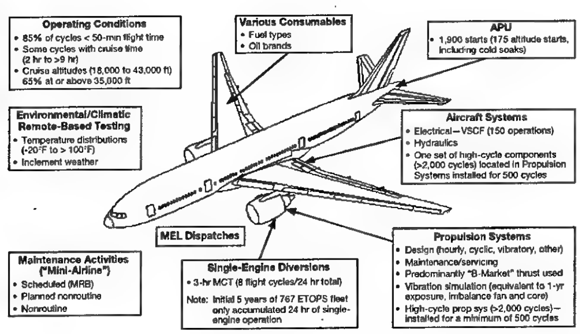


Figure 16. Validate the Airplane—1,000 Cycles and 1,400 hr

A LOOK BACK

It is over 2 years since the first 777 entered revenue service. Since that time, 95 airplanes have been delivered to 14 airlines and have accumulated in excess of 250,000 flight hours; three new Boeing derivative programs (737 Next Generation, 757-300, 767-400) have had the option of implementing the 777 processes or rejecting them. So, with all this time and experience behind us, is the Boeing 777 and its development process a success? I believe the answer is a resounding "YES!"

Industry certainly agrees, having recognized the 777 program with three awards:

1. The 1995 Collier Award for top aeronautical achievement.
2. The 1995 Smithsonian Computerworld Award for digital definition and preassembly in manufacturing.
3. The 1996 Smithsonian National Air and Space Museum Award for designing and building the most advanced and service-ready twin-engine jet in commercial aviation history.

Our customers, the airlines, clearly think so, having made it the preferred airplane. The 777 has achieved a 69% market share to date and is the single best testament to the perfect blending of functionality, reliability, and affordability. Pilots, flight attendants, and mechanics alike are enthusiastic about this airplane, as they should be, since it reflects so many of the features they requested through the working together process. I think Mr. Gordon McKinzie of United Airlines summarized it best: "Is this a great airplane, or what?"

Total program costs have been reduced when compared to a "business as usual" approach. These savings are primarily due to lower recurring costs from reduced change, error and rework by Engineering and Manufacturing. Comparisons with the 767 show approximately a 60% to 90% reduction in all change categories and fitup problems (figure 17). This results in less reengineering, less replanning, less retooling, less out-of-sequence work, less fleet retrofit, less warranty costs, lower inventory costs, less scrappage, less manufacturing flow, or, simply put, LESS COST! On the negative side, nonrecurring costs were increased due to the development and implementation of new tools and processes. Overall, however, a 15% to 20% savings in program cost is projected for the 777 (figure 18).

The airplane has demonstrated its service readiness, with a fleet average schedule reliability in excess of 98.6%, the best of any jet transport in its class at an equivalent time period (figure 19).

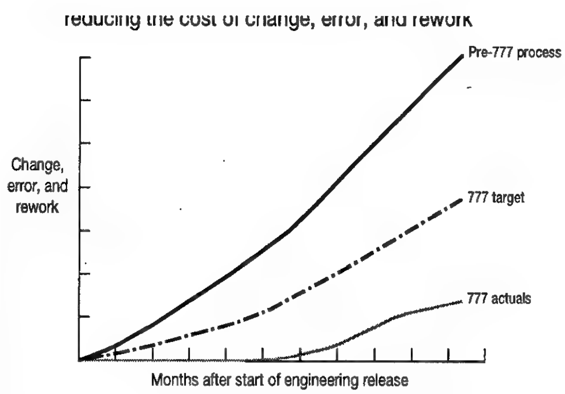


Figure 17. 777 Program Success

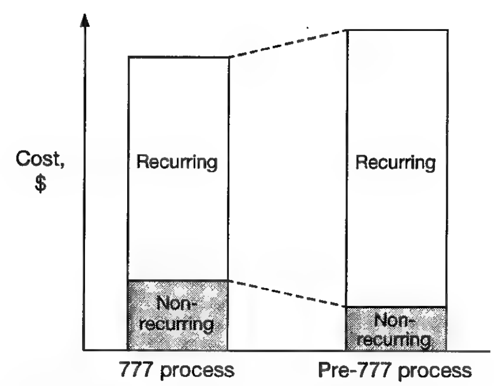


Figure 18. Program Cost Comparison—777 Process Versus Pre-777 Process

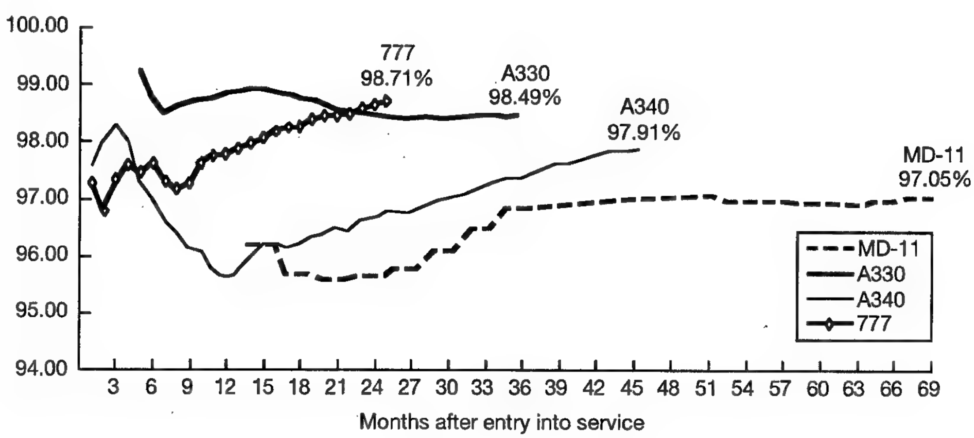


Figure 19. Entry Into Service Schedule Reliability—777, A330, A340, and MD-11 12-Month Moving Average

The 777 program success was made possible by the innovative way the airplane was developed. The specific processes used on the 777 have been carried over to the latest Boeing programs and will undoubtedly contribute significantly to their success.

The Design/Build Teams embodied the working together spirit and were absolutely essential to the success of the program. The teams brought together a wealth of knowledge and experience that no single individual had and thus permitted better decision making. Airline team members were especially effective, bringing their "real world" perspective to the team. It is a powerful process that generally became the magic solution to all problems. Technical or organizational issues were invariably solved by re-establishing or strengthening the working together activity.

Teaming does not, however, appear to be a natural human characteristic and did require training and continuous reinforcement and nurturing to prevent regression to the more individualistic attitudes.

Subsequent programs like the 737 Next Generation and 777-300 have recognized the importance of teaming to achieve reduced change, error, and rework, and hence cost, and have implemented a modified version with integrated product teams (IPT). IPTs are also cross-functional teams, but aligned by airplane volume, compared with DBTs, which are cross-functional teams aligned by commodity. While the IPT facilitates spatial integration, it complicates the functional and airplane-level integration that cross as multiple IPTs. The real key is not what the teams are called or how they are organized, but **WORKING TOGETHER** (figure 20).

Digital Product Definition (DPD) was the foundation for Digital Preassembly and was hence critical to meeting cost goals. It was essentially a totally new process that had been first used 4 years earlier in small pilot programs, such as to design hydraulic tubing for the 747-400 empennage. Significant training was required by all 777 team members to live in this new environment. DPD was found to place a significant burden on engineering, requiring approximately 60% more effort to develop a digital dataset than the equivalent 2D drawing. This was in part due to slow computing tools, where computer response time was sometimes measured in minutes. In addition, Engineering also became responsible for multiple models (e.g., solids, and wireframe) to satisfy requirements from downstream users. Lack of associativity between models further aggravated Engineering resource requirements. We also discovered that some outside suppliers did not have the capability to take advantage of the digital data in their manufacturing process. In spite of these early learning pains, DPD has become the accepted standard with the DPD "penalty" reduced to less than 10%. The use of faster computing tools and associativity between models, as well as knowledge-based product definition (automated design), is bringing us rapidly to the point where DPD, in its own right, is faster and cheaper. DPD will also form the basis for functional integration tools to reduce change, error, and rework, as well as risk, from systems interface and logic problems.

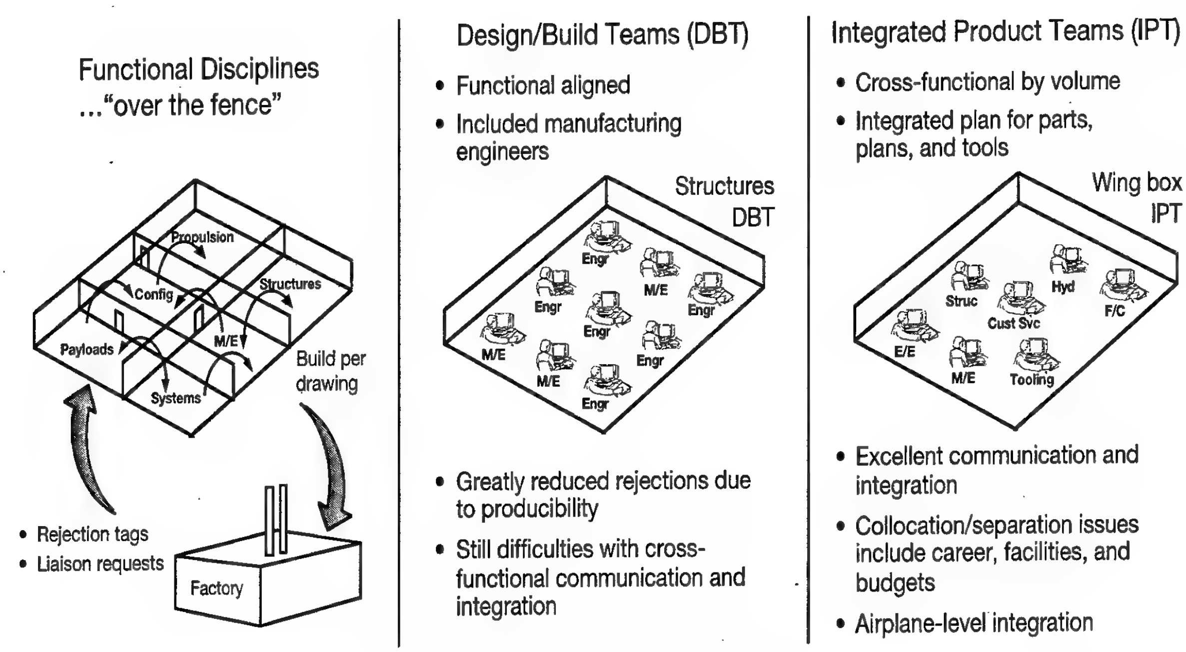


Figure 20. Evolution of Working Together

Digital Preassembly (DPA) at the airplane level was totally new and; learning how to use it effectively required significant on-the-job learning. With the introduction of Fly-Thru software, design reviews of the installation became very effective and in fact became the key means of ensuring cross-functional communication. While early emphasis was on interference checking, DPA rapidly came to be used to also check for producibility, maintainability, and safety. DPA did result in significant improvements in reducing interference and fitup problems in the factory. The assembly and installation of structures and systems is significantly easier and results in not just reduced cost, but also reduced cycle time. On a typical 777, four or five hydraulic lines out of approximately 1,700 require rework due to fit-up problems, compared to hundreds on a nondigital model.

Concurrent Product Definition (CPD) was used relatively successfully to minimize change, error, and rework. An integrated schedule was an absolutely essential tool in support of this process. Development was a complex cross-functional task that required detailed knowledge of what data are required to start a task, what follow-on activity the task supports, how long it will take, and the required completion date. System development plans, which were mandated early in the program, were very helpful in this regard. In spite of the emphasis on CPD, we did experience occasions where many design hours were spent refining installation only to start over because of late requirements, late analyses, or missing interface data.

Enhanced validation contributed significantly to reduced costs and service readiness. Numerous problems were identified early on by analysis, avoiding the much higher costs of fixing problems in test or in production.

Component and system testing in the lab further identified issues that reduced flight test risk and test time and provided sufficient time to correct the problems prior to delivery. The systems integration lab was particularly beneficial in identifying wiring and interface issues for electrical and avionics systems, as well as permitting dry running of airplane functional tests and flight test conditions.

The validation activity culminated in the most extensive flight test program ever. In nearly 1 year of flying, the P&W-powered 777 completed almost 1,600 flights for 3,600 hr. With a requirement to have essentially production hardware and software support the 1,000-cycle ETOPS program in November 1994, however, it was really the extensive analysis and lab testing that enabled us to meet the service-ready and ETOPS objectives.

CONCLUSIONS

The development of the Boeing 777 faced a significant challenge at its inception: how to create an airplane that was truly preferred by the airlines, at a price that was affordable. The program focused on two simple but powerful strategies: **working together and reducing change, error, and rework**. We used new and innovative tools and processes to implement these strategies. Looking back at the program today, 2 years after first delivery and 7 years after program go-ahead, it is clear that the two strategies produced a truly great airplane and forever changed the culture and processes at Boeing. The program laid the foundation for further improvements in tools and processes that will allow future programs to achieve even greater benefits in customer satisfaction and reduced costs.

THE DESIGN AND MANUFACTURE OF AN ALL-DIGITAL V-22

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Abstract

The production V-22 has incorporated the latest technologies and computer-aided techniques and manufacturing processes:

1. CATIA™ (Computer-Aided Three-Dimensional Interactive Application) for design. A single authority digital data base that contains all the design information.
2. Digital electronic mockup (EMU) to determine part fit-up and resolve interface problems during the design phase through Digital Pre-Assembly (DPA), instead of creating panic on the assembly line.
3. Concurrent Product Development using over 80 Integrated Product Teams (IPTs) consisting of engineering, tooling, manufacturing, supportability and subcontractor disciplines, working simultaneously on each major part of the aircraft to ensure a "balanced" design. The multiple customers for the V-22 aircraft, USMC, USN, and USAF/SOCOM, are an integral part of the IPTs. An Analysis and Integration (A&I) team ensures consistency across interfaces and an Integrated Test Team (ITT) of contractor and customer personnel perform flight testing.
4. Manufacturing process improvements including the utilization of part features to locate and assemble components; fiber placement of large pieces of composite structure with simple and compound curvature; high speed machining of large monolithic pieces of metallic structure rather than assembling them from pieces; laser optical layout templates driven from the CATIA™ data base to locate composite plies during lay-up; robotic trim and drill cells; automated creation of wiring form boards and numerically controlled, CATIA™ driven, automatic bending of hydraulic tubes.

The results of using these new technologies and processes are compared with 1980's methods.

Presented at the NATO/AGARD Flight Vehicle Integration Panel Symposium, 22-25 September 1997, Drammen, Norway

Introduction

The V-22 tiltrotor is a unique rotorcraft that can efficiently hover like a conventional helicopter and fly at speeds above 300 knots with the efficiency and comfort of a turboprop airplane. Developed by a team from Bell-Boeing for the U.S. Marines, Special Operations Command (SOCOM), and Navy, six aircraft (tail numbers 1 through 6) designed, built, and tested during the Full Scale Development (FSD) phase, have completed over 1100 hours of flight test. The program is currently in the Engineering and Manufacturing Development (EMD) stage in which four new aircraft (tail numbers 7 through 10) have been built on production tooling. These aircraft are now in flight test at Patuxent River. The plan for the overall development program is presented in Figure 1. Testing will cover all of the structural features of the airframe and the basic USMC avionics and will be completed in 1999. The development and test of the SOF and Navy CSAR configurations which use the same basic airframe but incorporate changes and additions to systems and avionics will continue into the early 2000's.

Although the tiltrotor concept was studied in the 1930's and experimental aircraft were built in the 1950's and 1970's, there were two enabling technologies that matured in the 1980's and allowed a viable production design possible. They were fly-by-wire (FBW) all-digital flight control systems and composites technology for primary structure. The FBW control system allowed an automatically re-configurable control system for all modes of flight and made it easier to design the wing stow system at an acceptable weight. Composites technology provided the choice of materials for optimum design of the structure to meet dynamic characteristics, and strength, cost and weight targets.

Some of the salient design features of the V-22 are shown in Figure 2. The V-22 carries a crew of two to four and has the capability for seating 24 combat troops. Flexibility is added by the ability to carry external cargo up to 15,000 pounds on tandem hooks with individual capacities of 10,000 pounds. An aft ramp allows rapid loading and unloading of internal

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

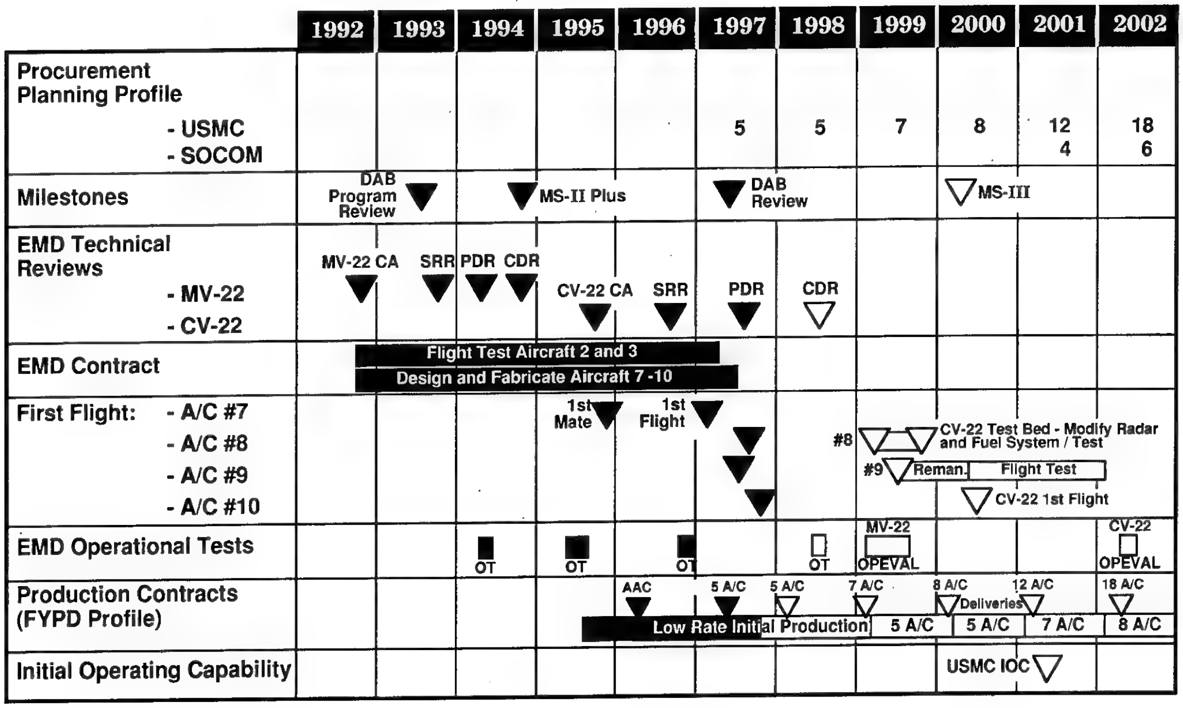

Figure 1. V-22 EMD / LRIP Program Schedule

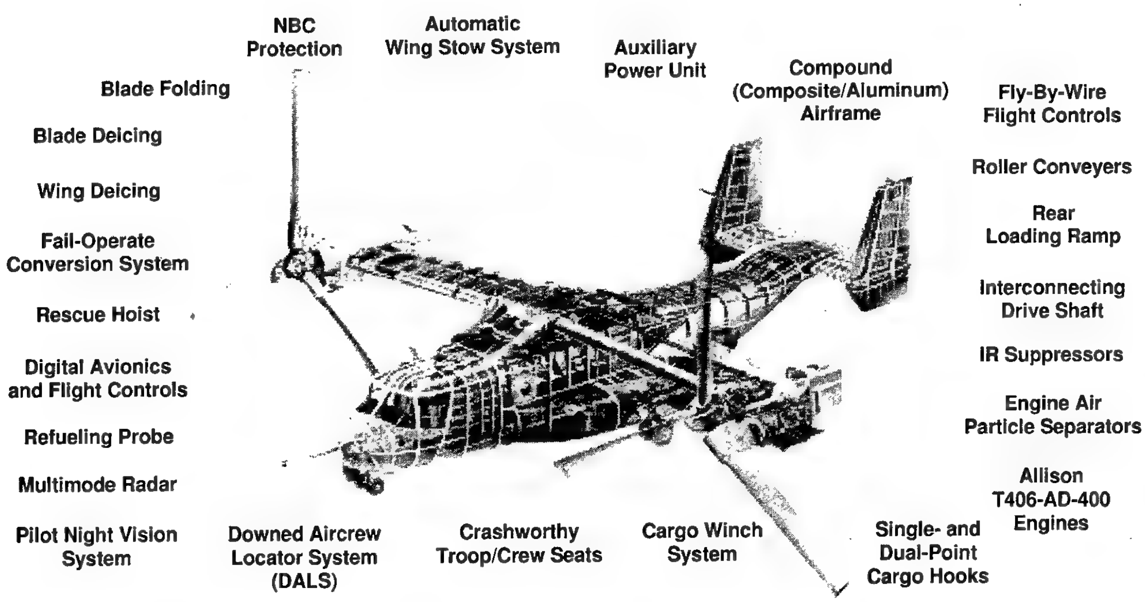

Figure 2. V-22 Multi-Mission Features

cargo. The rotor blades fold and the wing rotates for stowage aboard ship. The V-22 is capable of all-weather instrument flight, day or night, and continuous operation in moderate icing conditions, and at weights up to 60,500 pounds for self deployment. The V-22 structure uses the latest in composite materials and manufacturing processes. A synergistic combination of precision machined aluminum, fiber-placed graphite, and titanium has allowed a significant weight reduction in the EMD V-22. The Night Vision Goggle-compatible cockpit includes conventional controls and digital avionics displayed on four Multi-Function Displays (MFDs) and one Control Display Unit/Engine Indicating and Caution Advisory System (CDU/EICAS).

Mission Performance

The V-22 is a highly flexible, multi-purpose aircraft capable of performing many missions. The V-22 has been the winner in over thirty different mission sce-

narios identified and evaluated by the US Government, Bell-Boeing, and independent analysis companies.

The multiple design mission key performance parameters (KPP) and aircraft capabilities are presented in Figure 3. The V-22 meets or exceeds all mission requirements. In addition, the independent variables used in the compliance calculation all have built-in buffers to ensure that the required KPP's are met at the end of EMD in 1999.

	Key Performance Parameter	MV-22 Projection	CV-22 Projection
Pre-Assault / Raid (18 Troops)	200 NM	214 NM	–
Land Assault (24 Troops)	200 NM	275 NM	–
Land Assault (10,000 Lb Load)	50 NM	50 NM	–
Amphibious Assault (24 Troops)	2 x 50 NM	2 x 71 NM	–
Amphibious Assault (10,000 Lb Load)	50 NM	111 NM	–
Self-Deploy (With Refueling)	2100 NM	2565 NM	2627 NM
Long Range SOF Missions	500 NM	–	503 NM
MV-22 Cruise Speed (V_{MCP} at 3000 Ft / 91.5°F)	240 Knots	275 Knots	–
CV-22 Cruise Speed	230 Knots	–	261 Knots
Survivability	12.7 mm	12.7 mm	12.7 mm
V/STOL / Shipboard Compatible	Yes	Yes	Yes
Aerial Refueling	Yes	Yes	Yes

Figure 3. V-22 Projected Capabilities for Prime Missions

For the Marine Corps, the Osprey's speed and range provide an expanded battle-space that complicates the enemy's ability to defend their territory. Figure 4 shows the increased combat reach the Marines will have while making an amphibious assault, relative to the capability of the present Marine assault medium lift aircraft, the CH-46. The range capability of the Osprey permits the amphibious fleet to use the sea as operational maneuver space. This increased capability allows greater standoff distance for the amphibious fleet, thus avoiding coastal minefields and missile defenses. It also enhances the element of surprise by providing a capability for feint and deception.

Special Operations Forces (SOF) require high-speed, long-range V/STOL aircraft capable of penetrating hostile areas. The SOF variant of the V-22 will meet this requirement. The SOF V-22 is capable of covert penetration of medium to high threat environments in low visibility, while employing self-defensive avionics and secure, anti-jam, redundant communications. The SOF V-22s inherent long-range and self deployment ability maximizes mission security and minimizes logistics cost. It has an unrefueled combat range sufficient to satisfy current and emergent military needs and carries a built-in refueling boom for range extension. The SOF V-22 has the necessary speed to complete most operations within one period of darkness and can operate from air capable ships without reconfiguration or modification.

Figure 5 portrays the potential advantages of using the V-22 in the initial stage of "Operation Eastern Exit", the evacuation of 61 Americans and several foreign Ambassadors from the US Embassy in Mogadishu, Somalia. The actual evacuation by CH-53Es, carried to waters off Somalia by the USS Trenton (LPD-14) from its anchorage off Oman, took 87 hours and included three aerial refuelings per helicopter. With the V-22, the same mission could have been flown directly from Oman using two aerial refuelings with a total mission time of less than seven hours.

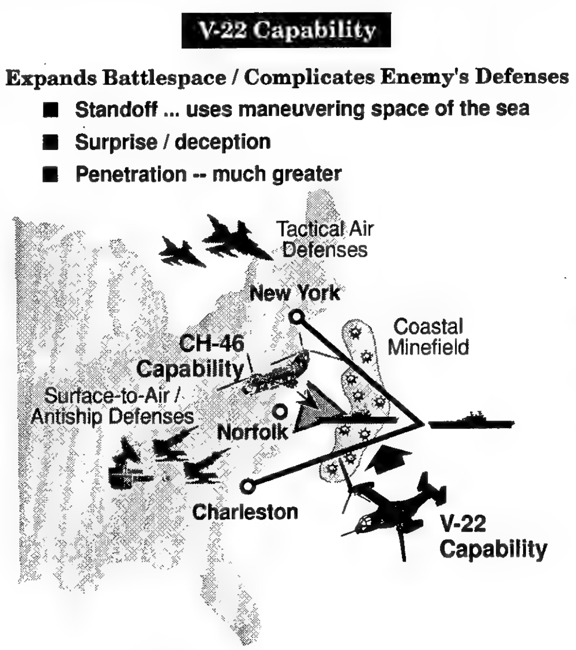

Figure 4. Enhanced Reach in War

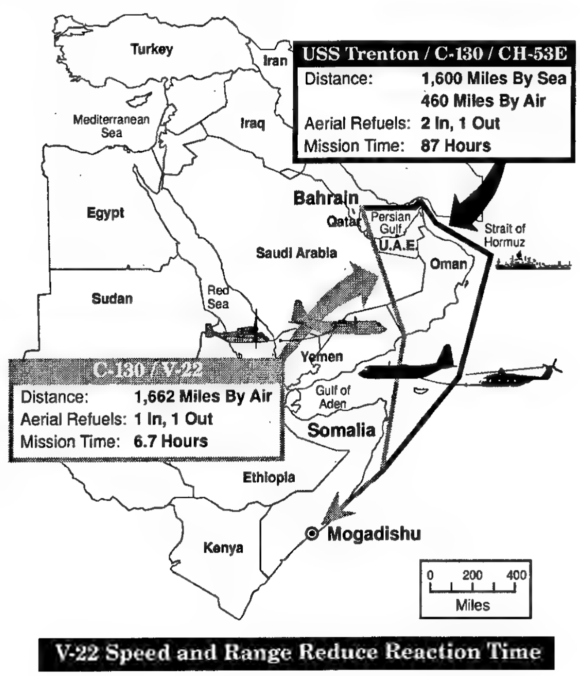

Figure 5. Operation Eastern Exit - Comparing Helicopter and V-22

Similarly, in an April 1980 attempt to rescue US embassy personnel in Iran, an 87 hour mission could have been performed by the V-22 in less than 7 hours without the attendant problems of refueling at Desert One.

Search and Rescue variants of the V-22 have been studied for the US Navy Combat Search and Rescue (CSAR) mission and for civilian SAR applications. Typical SAR missions often require extended range and speed combined with extended time-on-station to perform the necessary search. The ability to combine speed, range, and time-on-station with the ability to hover and recover victims, means the SAR V-22 can provide a great improvement over the current necessity for combining fixed-wing aircraft for search and land or ship-based helicopters for pickup.

An illustration of the SAR capability of the V-22 is shown in Figure 6. Flying from bases in Norway, the V-22 could perform SAR missions covering all of Norway and the surrounding seas.

SL/ISA; 1 Hour Loiter; 4 Rescuees;
7,825 Liters Fuel; Includes 1,210 Kg Fixed Useful Load

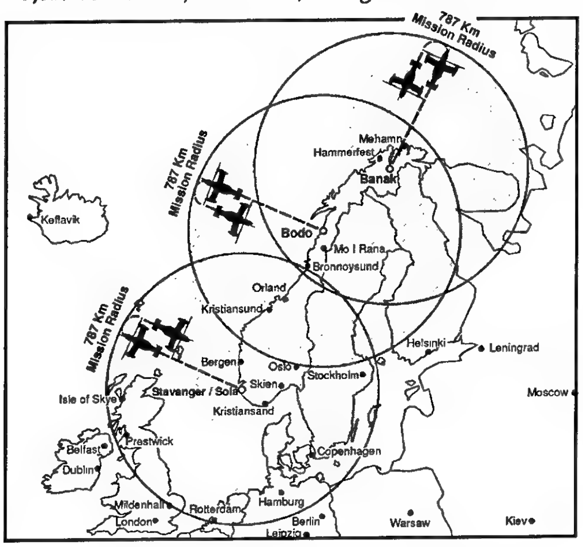

Figure 6. V-22 Osprey Search and Rescue

Design and Manufacturing Processes

Past experience indicates 80% of a product's life-cycle cost is determined by decisions made during the first 20% of the product design cycle, a fact which encouraged Bell-Boeing to adopt a new approach to designing the production V-22 which would ensure that robust decisions were made during the crucial early stages of design.

Concurrent Product Definition (CPD) includes near-simultaneous design, analysis, and planning by engineering, manufacturing, logistics support disciplines, and active participation by the customer. This leads to reduced flow times, lower procurement and operating costs, and higher quality products. The traditional, functional product development flow had organizational barriers between critical areas like engineering, planning, tool fabrication, and manufacturing. These barriers inhibited good communication during the critical engineering, manufacturing, and product support phases.

The CPD approach integrates all disciplines from the beginning of the product development process using Integrated Product Teams (IPTs), a functionally transparent management approach and a single digital data base for all product information.

Over 80 IPTs consisting of engineering, tooling, manufacturing, customer, supportability and subcontract disciplines, worked simultaneously on each part of the aircraft to ensure a balanced design. They had the authority and responsibility (including budget) for their portion of the product. At the major system level, Analysis and Integration teams (Segment A&Is) ensured consistent application of requirements by the teams with allocation and mediation of requirements across interfaces. Typical parameters that were allocated to the IPT's were weight, drag, reliability, maintainability, design-to-cost, life-cycle cost, subsystem cost, etc. Above the Segment A&Is, the Air Vehicle A&I ensured overall consistency and adjudicated conflicts. The multiple customers for the V-22 aircraft are an integral part of the A&Is and IPTs.

The tool that facilitates all IPT activities is the graphics-based CATIA™ software. It provides a single-source, computer-generated, three-dimensional definition of the total product and its individual parts. As illustrated in Figure 7, CATIA™ facilitates the cross-talk among all functional disciplines from preliminary design to product support.

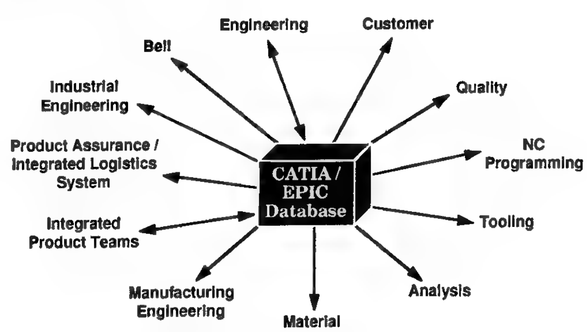

Figure 7. CATIA™ / IPT Processes

CATIA™ allows the creation of three-dimensional models such as the landing gear bay shown in Figure 8 (very similar to virtual reality) that permit engineers to assess designs early and eliminate the building of

expensive hardware mockups. The elimination of hardware mockups (difficult to maintain in the latest configuration) saved 150,000 man-hours on the V-22 EMD program. Parts are then digitally pre-assembled to catch design errors early, when changes are least expensive, prior to fabrication.

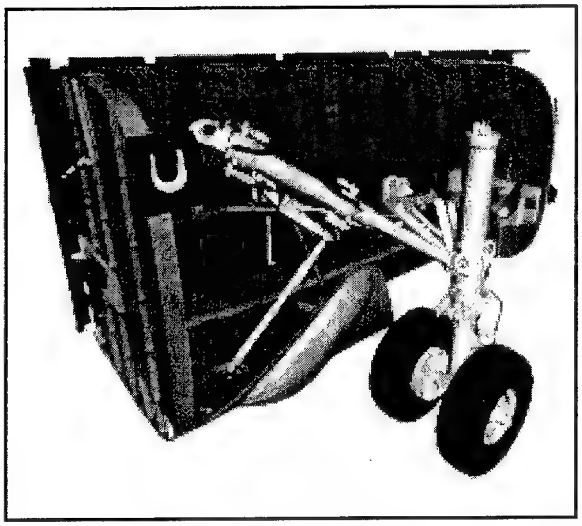

Figure 8. Landing Gear Solid Model

VERICUT™, a tool for providing Numerical Control programming concurrent with product design, uses the same CATIA™ data base. The NC programmers "fabricate" their part electronically (using VERICUT™) to determine cutter feeds and speeds. Once the part has been "electronically fabricated" the original design model is over-laid on the fabricated part and any areas of divergence are immediately apparent to the NC programmer who can then take appropriate corrective action.

VALISYS™, a valuable quality control software tool also tightly integrated with the CATIA™ system, provides a necessary link between engineering and manufacturing. It provides the capability to check the engineering design to verify and ensure that the geometric dimensioning and tolerances are correct to the standard, and it allows part tolerances to be represented in the three-dimensional models. Where these tolerances are critical for the assembly of detailed parts, they are labeled as key characteristics.

Since variations can occur during manufacturing, VALISYS™ performs quality checks to ensure that part integrity is maintained throughout the fabrication process. VALISYS™ helps design quality into not only the product, but also the manufacturing process.

Using CPD, IPTs, DPA, VERICUT™, and VALISYS™ lowers cost and increases product quality. These benefits were validated early in the product development process and disseminated to the IPTs if corrective action was required. The result has been increased quality because individual parts are designed with producibility and ease of assembly considered from the beginning; this, in turn, permits proper manufacturing tolerances and decreased variation so parts fit correctly the first and every time. As an example, the three sections that comprise the V-22 airframe were successfully mated in one-half hour (excluding fastening). In FSD this process took several days.

Manufacturing Technologies and Systems

To develop the V-22, Bell-Boeing is incorporating some of the most technically advanced manufacturing systems available today. These systems are integral parts of the CPD process, and Bell-Boeing is investing in them to take full advantage of the cost and economic benefits they generate for military and commercial applications.

When comparing the traditional manufacturing technologies employed on the FSD V-22, to the advanced systems being used to manufacture the EMD configuration, the evolution is profound. Now, advanced machines, utilizing the CATIA™ database, robotically manufacture large, one-piece composite sections and high-speed-machine single-piece aluminum frames from billets for the V-22. These systems allow engineers to eliminate hundreds of parts and dedicated tooling. Four important systems being used are optical lay-up template, trim and drill cell, advanced technology assembly, and fiber placement.

Optical Lay-up Template

For flat or simple contour parts, hand lay-up using composite broad-goods is often the manufacturing process of choice. To improve the efficiency of hand lay-up, new technologies and manufacturing concepts are being used to build the V-22. Bell-Boeing has implemented a new, laser-based ply locating system called Optical Layup Template (OLT) in the composite manufacturing facility. The system combines laser technology and various optical components with data supplied by CATIA™ to project a three-dimensional image of a detail onto a contoured lay-up tool, Figure 9. This three-dimensional capability means the laser line will conform to ply lay-up surfaces, thus eliminating the need for labor-intensive locating templates previously needed to fabricate composite parts. Coupling OLT with CATIA™ allows changes to engineering designs to be made instantaneously with no need to fabricate new templates. Reduced template fabrication results in major savings in the cost of producing storing and maintaining expensive templates.

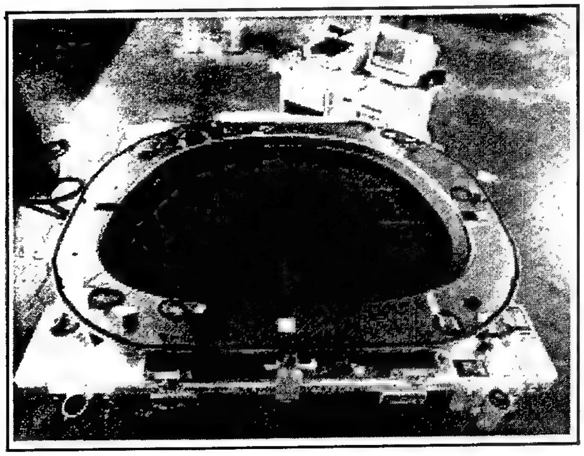

Figure 9. Optical Layup Tool

Trim and Drill Cell

The Trim and Drill Cell combines the latest technologies in locating, fixturing, trimming and inspecting composite parts. Parts are located in the cell utilizing a universal holding fixture that is programmed from data downloaded from CATIA™ to match the part contour. This process has eliminated the need for individual trim templates for every part, reducing non-recurring tooling costs and recurring tool maintenance costs. The parts are trimmed utilizing an abrasive water jet system, a very high velocity water stream with abrasive particles. The cell then installs locating and tooling holes utilizing a precision drilling head and inspects the parts before it is removed. By combining the direct use of the single source digital data and the repeatability of an automated machine tool, recurring costs are reduced and product quality is significantly improved while reducing variability.

Advanced Technology Assembly

Advanced Technology Assembly (ATA) is another process being used in manufacturing to support the CPD process. ATA is used to precisely locate machine drilled holes in aircraft parts that are subsequently used to assemble the detail parts. The application of this process is made possible through the use of the single source 3D CATIA™ data base. Early in the design process the manufacturing engineers and tool designers determine the location of these coordination holes. These holes are then firmly fixed in the engineering 3D dataset to ensure coordination throughout the design and fabrication process. The application of this technology significantly reduces the non-recurring tooling required for assembly tooling as the part is its own tool. This again eliminates the recurring cost to maintain and modify these tools downstream.

Fiber Tow Placement

Fiber tow placement technology is an important part of the effort to reduce V-22 cost and cycle time while improving quality. Fiber tow placement provides the means to automate the lay-up of composite materials in complex convex and concave surfaces while maintaining precise quality standards. Fiber tow placement eliminates the need to create sheets of composite material, cutting them to size, and laying them up on a tool by hand. A fiber tow placement machine in Figure 10 creates a ply from strands of one-eighth inch-wide fiber tape, or tows, as the tape is laid up on the tool.

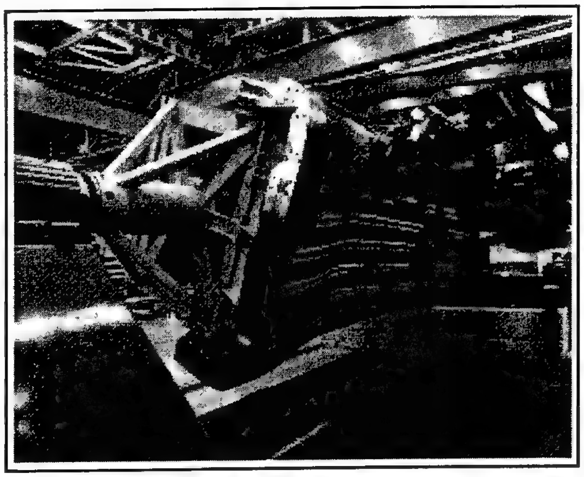

Figure 10. Fiber Placement of Aft Fuselage

This system is an important part of the CPD process using 3D digital data to perform its assigned tasks. The fiber placement system, coupled with CATIA™ capabilities, has changed the way V-22 composite parts are built. These types of capabilities equate to significant savings in labor. For example, 70% reductions in trim and assembly labor and 50% in composite manufacturing labor have been achieved.

Significant Improvements From FSD To EMD

There are many success stories in all facets of the EMD design and manufacturing. We will describe a few in this section and show some appropriate improvement metrics.

- Weight reduction
- Design to cost (DTC) reduction
- Wing stow system redesign
- Aft fuselage section redesign
- Aircraft fuselage redesign
- Aluminum frame high speed machining
- Rejection reports
- Integrated testing

Weight Reduction

At the end of the FSD program, the weight empty of the V-22 aircraft had grown to almost 35,000 pounds. At

the beginning of the EMD design phase the data bank of weight reduction ideas left over from the FSD phase was distributed to the IPTs and used in the design effort to drive the weight down by 2828 pounds. This resulted in a weight empty of 32,105 pounds in January 1993 (Figure 11), just after EMD contract award. As of May 1997 , over four years later, the status weight is 32,270 pounds. The weight empty is expected to be under the specification weight empty of 33,140 pounds at the end of OPEVAL. All performance predictions and guarantees have been made at the higher weight for conservatism.

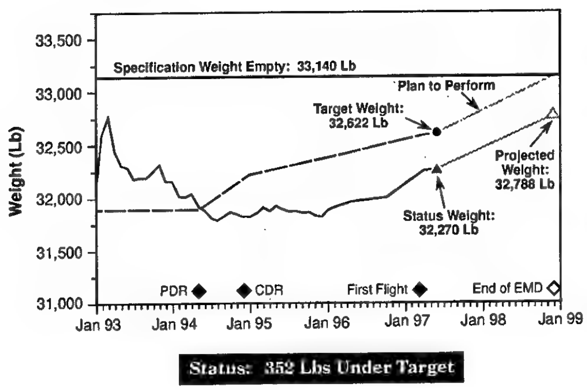

Figure 11. Weight Empty History

Design-to-Cost Reduction

The changes that were made to the FSD design and manufacturing processes were also instrumental in reducing the unit cost. Figure 12 shows a steady decrease from \$41M in January 1993 to the present \$32.2M, a decrease of 23%. The \$32.2M cost can be reduced further by up to \$4.1M per unit by including currently identified Cost Reduction Initiatives (CRIs) and Producibility Improvement Plans (PIPs), and programmatic initiatives such as multi-year procurement. If the total package of identified initiatives is implemented the total unit cost reduction from FSD can be as high as 33%.

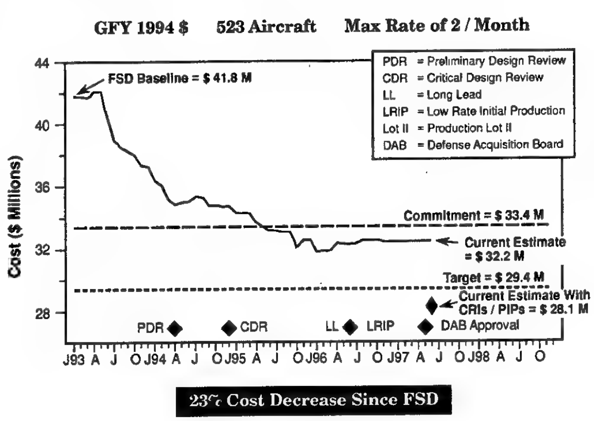

Figure 12. Recurring Flyaway Cost Estimate

Wing Stow System

To minimize aircraft spotting factor and minimize readiness time (when aircraft are brought to the flight deck from hangar deck storage) the V-22 was required to automatically fold into a compact size in 90 seconds. The folded aircraft is shown on the side elevator of an LHD in Figure 13.

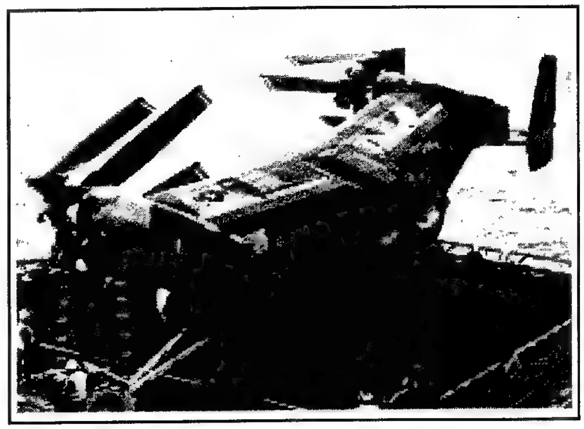

Figure 13. Folded Aircraft

By redesigning the FSD wing folding system the weight was reduced by 300 pounds and the cost by \$200,000 per aircraft. Also the system is now easier to install and access to components under the wing is greatly enhanced.

Aft Fuselage Section

The FSD aft fuselage, from the rear ramp hinge to the attachment of the empennage, was designed to combine 9 hand lay-up skin panels and 157 stiffeners.

During the EMD redesign for producibility the skin thickness and stringer/frame placement was thoroughly examined to optimize the use of the fiber placement equipment. The result is a one piece fiber placed skin with 17 cocured continuous stringers and a total cost reduction of 53%.

Aircraft Fuselage Redesign

A summary of the significant cost drivers, parts count and fastener count, for the forward, center, and aft fuselage sections are shown in Figure 14. In both cases

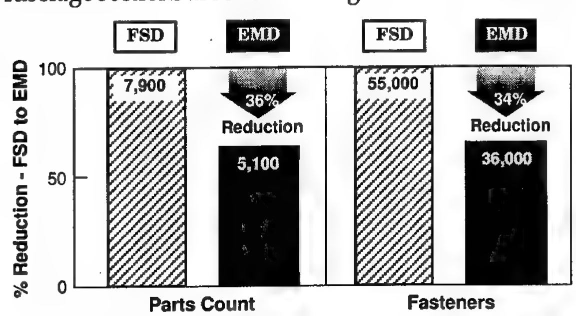

Figure 14. Fuselage Modules - Parts Count and Fastener Reductions

the reduction from the FSD design to EMD is about one-third. For fasteners this reduction has a profound effect on cost because each fastener needs to be procured, the hole must be located, drilled and inspected, and the assembly inspected again after fastener insertion and tightening.

Aluminum Frame High Speed Machining

One of the most significant early design decisions in EMD was the granting of authority to the IPTs to optimize materials use. During FSD the whole primary structure was designed in graphite composites. In EMD most of the complex frames were produced by high-speed machining of aluminum. The results were extremely favorable, as shown on Figure 15. Not only were part count (39 to 1), fastener count (258 to 0) and tool count (46 to 2) reduced with an attendant reduction in cost of 37.5%, surprisingly, the weight of the part was also reduced from the all-composite unit by 18%. This indicates that a very careful choice of materials and design must be made to achieve the optimum solution.

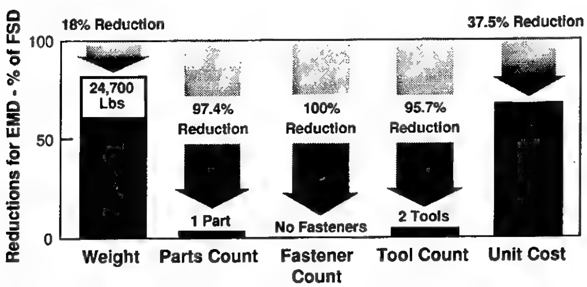

Figure 15. Aluminum Frame High-Speed Machining

Rejection Reports

As a visual summary of the concepts discussed earlier, Figure 16 shows that Rejection Reports, a metric of the problems encountered in the manufacture and assembly phases, have been reduced by 60% from FSD to EMD.

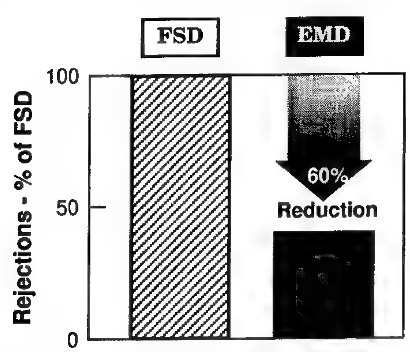

Figure 16. V-22 Rejection Reports - FSD to EMD

This means less scrap, less rework, less handling of parts, less shortages, less out of sequence installs, and translates directly into less unit cost in production.

Integrated Testing

In February of 1993, the US Navy's V-22 Osprey Program Management Team established a new way of managing its flight test program based on the Air force Combined Test Force concept.

The ITT is an IPT within a much larger IPT organization that includes design and manufacturing as well as flight test. From the beginning, government and contractor managers agreed that the best way to make the ITT concept work was to truly integrate all personnel by physically locating them side-by-side. No one was excepted. Pilots, engineers, managers, and maintainers were all co-located to maximize interaction, communication and awareness of potential changes.

The Flight Test Review Board (FTRB) is a major success for the ITT. The premise behind the FTRB was to reduce, or eliminate the need for deficiency reports because they are written too late in the acquisition process. At the Board all "squawks" are reviewed and defended by the author to ensure adequate justification existed for generating the "squawk", if so, the "squawks" are handed to Bell-Boeing representatives for correction and/or disposition.

During EMD an integrated customer Development Test/Operational Test (DT/OT) effort is planned. This means that the OT personnel will form a detachment to work closely with the DT personnel. Even with the operational testers participating in DT they will still conduct an independent OT and operational evaluation (OPEVAL). It is expected that the familiarity they gained during DT participation will reduce the need for proficiency flying prior to their dedicated operational test periods.

Concluding Remarks

The V-22 is an extremely capable and uniquely versatile vehicle that has developed and incorporated many new and exciting technologies. These include design and manufacturing processes, as well as innovative new analysis and test methods. The V-22 team is looking forward to the MV, CV and other exciting derivatives reaching their operational units. We expect that the aircraft will be equally useful to US friends and allies.

THOMSON-CSF EXPERIENCE IN AIRBORNE SYSTEM INTEGRATION

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Foreword

The strategic management of the cost issue is of major importance for any company ; basically, the question is to combine the customers' satisfaction and the company's profitability. The customers' satisfaction is met with agreeable and affordable levels of price and performance of the products and systems they buy. The company's profitablility is needed to meet the basic rules of capital and strategic investment.

In our so called "high tech" companies we have also to take account of the huge level of R and D required to run our projects and programs. More and more, this R and D is partially, if not totally, self -funded by the company itself.

Furthermore, cost management must enable us to get the resources which are needed to be in the position to study, then develop and produce the future systems which will be in the Forces, our customers.

Many answers can be given to this difficult question of cost management.

After having introduced my company, THOMSON-CSF/Radars et Contremesures (RCM), and our main airborne systems, I will address our global methodology dedicated to these systems' studies and developments. This methodology, without any doubt, is the fundamental core of our know-how, not only relying on more or less heavy and sophisticated tools, but also and above all fed by the unique skill of our staff, for decades.

Presentation of charts 1 to 6 (RCM and its products and systems overview)

1. INTRODUCTION (CHART 7)

The ultimate aim of any project or program is to respond to a customer requirement. No company can hope to develop—or even survive—unless its customers are satisfied and unless the work for which it is responsible has been carried out in line with forecasts, particularly cost forecasts.

These basic truths are applicable to all types of products and systems, however complex.

- To satisfy a customer, the customer's requirement must first be understood.
- Then there is a need to agree with the customer on the best way of satisfying this requirement with the budget available.
- Finally, the customer must be shown that the requirement has been met, logistic support must be provided as agreed, and subsequent system developments must be proposed if and when the operational context changes.
- In the view of the operation being profitable for the company, there is a need to monitor each step in the program, control the risks involved, and take corrective action as soon as variances or overruns are detected.

There is now a generally accepted working methodology .This presentation does not go into detail about the methodology itself, but uses the basic schema (chart 8) to structure a description of the tools used at successive stages of an onboard systems program.

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

- Understanding the customer's requirement (chart 9). Technico-operational simulations, usually man-in-the-loop simulations in real time, are used at this stage. The main example is the METRO simulator.

- Designing systems, developing specifications for the different components (chart 10) and setting operational limitations. Modeling tools are used to model individual items of requirement as well as interactions and possible interference between these items of equipment. The main example used is the SARGASSES simulator.

- Proving that behaviour and performance levels observed experimentally are the same as were predicted and modeled (chart 11).

This needs to be done as early as possible and as soon as the actual components or items of equipment are available. The main example used is Le Mengam test base.

- Showing the customer that the system that will be delivered is really what had been agreed to and satisfies the requirement that had been expressed (chart 12). The main example used is the Thomson-CSF test facility at Brétigny.

All the major companies working in this field use tools of this kind. The capabilities of each tool and the level of coherence between them largely depends on how much has been invested to develop them.

There is such a variety of problems that need to be solved in onboard systems—and the systems themselves are becoming more complex and budgets are getting tighter— that no single electronics company or aircraft manufacturer can hope to maintain all the skills needed all the time. Cooperation is of critical importance.

For onboard systems, there is a clear need for cooperation between aircraft manufacturers and suppliers of electronic systems. Cooperation is also vital between industries and government bodies in the same country or in the other countries taking part in joint programs. Everybody will benefit from effective partnership or closer international cooperation.

2. UNDERSTANDING THE REQUIREMENT (CHART 13)

Understanding the requirement is the most vital link in the system design-production-integration process.

All programs are affected by today's budget restrictions. Right at the beginning of each program, and, regrettably, also while the program is being conducted, successive trade-offs must be made between the operational requirement as expressed, the technical performance needed to meet that requirement, and cost.

These trade-offs are basically achieved on a consensual basis by operational staff or end users, the government bodies in charge of the program, and contractors. It is therefore a question of teamwork. Everybody has to understand the other team members' points of view, and the contractors in particular have to propose price-performance trade-offs that are acceptable to their partners.

Knowing what each solution would cost—which can be difficult in an area that is changing so fast—is clearly crucial to this process of optimization.

This is, and will continue to be, the contractor's basic job. Contractors that want to stay in the running will have to get better at assessing the exact cost of the different solutions.

Knowing how the technical requirement that generates this cost will affect operational performance—which is what end users need to know—is a rarer skill. This is one of the distinctive competencies of the systems supplier.

In many fields, including onboard systems, numerical simulation has become indispensable.

The example given on the chart (chart 14) and shown later in the movie involves real-time man-in-the-loop simulation of air-to-ground functions from combat aircraft or helicopters.

Distributed Interactive Simulation (DIS) standards are used to achieve interoperability between various computing devices installed in different locations, with a view to simulating :

- the environment and its visual representation,
- the aerodynamic behaviour of the platform,
- various air defence systems,
- various self-protection systems,
- various air-to-ground weapons.

The aim of simulation in this case is to assess the probability of destroying a target protected by air defence systems, and to assess the survivability of the aircraft in various self-protection configurations (warning detection, jamming, deception).

The METRO simulator has a lot in common with a pilot training simulator, and was jointly developed by the Thomson-CSF units in charge of training simulators (TT&S), air defence systems (Airsys) and onboard systems (RCM). It is a good illustration of the benefits of using standards and standardised procedures. With this approach, different players in a system can set up a real-time computer model, or a hybrid model incorporating items of real equipment—without all needing to be in the same physical location, and without having to exchange detailed models of the equipment or subsystems for which they are responsible.

This type of tool is already sufficiently mature to gauge how sensitive a given aspect of operational performance is to different technical parameters when the simulation is controlled in real time. Using these tools is an ideal way of achieving the dialogue and mutual understanding needed to define complex systems.

But the complex-system integrator's job does not end here. Once the requirements have been understood, it must be established that the concepts selected are feasible in practice, operational limitations must be stated, risks must be qualified and needs expression and feasibility must be fed into the loop—sometimes with several successive iterations—before a mutual agreement can be reached and the contractor can make a formal commitment to the customer.

The next part of the presentation deals briefly with this second category of tasks, which are generally conducted by industries and often on a cooperative basis.

3. RISK ASSESSMENT (CHART 15)

Customer satisfaction depends above all on how well we have understood that customer's requirements. Similarly, the industrial success of a program (in terms of the level of satisfaction of the company's financial director) will depend on how well we have assessed the risks involved and applied the right procedures to reduce those risks to acceptance levels when we made the commitment to the customer.

Here again, usually still at the stage when neither the platform nor the equipment making up the system actually exist, numerical simulation is an essential tool, provided it is used by experienced teams—i.e., teams that have already compared simulations and measurements and that have not lost touch with the practical sense of the engineer.

Major areas of risk for aeronautical systems include :

- Resistance to vibration and impact (deck landings, extreme climates, depressurisation, etc.) (Chart 16)

  The real difficulty is to determine the conditions that will be encountered in real life, as compliance with standards is no longer a sufficient argument in itself and rarely leads to cost optimization.

  In this case, the best chances of success lie in a high-quality relationship between the aircraft manufacturer, who knows the platform better than anybody else, and the equipment supplier who knows the equipment. When aircraft manufacturers and equipment suppliers have gained their experience by working together, this relationship can be of very high quality, and this is an argument in favour of strong partnerships in this area.

- Electromagnetic compatibility is a growing risk, not only because the signals transmitted cover a broader spectrum and threshold voltages on logical gates are lower, but also because modern aircraft are equipped with large numbers of powerful transmitters and highly sensitive receivers.

- Assessment of flows of numerical data, computing times or transmission times are also areas of risk. The chart 17 shows the growing part of electronics since decades, and the induced growing complexity in the airborne systems.

  Assessment of the effects of nearby structures on antenna radiation patterns
  This is often of crucial importance and can lead to a long iterative process with the aircraft manufacturer and the customer.

  Today, a sophisticated electronic warfare system such as the ICMS for the Mirage 2000-5 (Chart 18) can have up to 25 antennas, all additional to the many antennas or aerodynamic sensors that equip the basic airframe. Each antenna in the electronic warfare system must be located in the best possible place on the aircraft, taking into account the pods, weapons or different antennas carried by the aircraft.

  This is a very important problem that requires a very high skill. The objective is to find compromise solutions, and at the very least to identify system limitations and make sure the customer is aware of those limitations.

  This was Thomson-CSF's objective when it developed SARGASSES (chart 19).

  A few comments should be made here about using SARGASSES :

- Results are best when the aircraft can be described in precise detail. Here again, a good relationship between the aircraft manufacturer and the electronic system supplier is extremely important, as only the aircraft manufacturer has the exact computer description of the aircraft.

- SARGASSES can also be used to calculate the radar cross-section of all types of objects. Results are remarkably good.

4. VALIDATION OF TECHNICAL PERFORMANCE (CHART 20)

Using the examples taken to illustrate the major areas of risk, we will now describe the equipment used to check that predicted performance levels are really achieved, to make sure that the risks have been overcome, and to convince the customer that this is the case.

- Mechanical and thermal resistance : conventional equipment such as vibration generators, thermal chambers and depressurisation chambers are used here.

  The modeling is of excellent quality. Referring to vibration on an equipment cabinet, calculated and measured resonance frequencies are only a few thousandths apart.

- Electromagnetic compatibility : individual items of equipment, cabling and, whenever possible, whole systems, need to be tested to avoid costly electromagnetic compatibility problems when they are integrated on board the aircraft.

- To control flows of numerical data and more generally to monitor system operation on the ground, specific system assembly or integration test benches need to be developed.

  The chart (Chart 21) shows the assembly bench for the ICMS integrated countermeasures suite.

  The equipment is interconnected, and each item of equipment can be replaced by a behavioural simulator. We feed the system either with data flows generated by initial modeling sequences, or by using hybrid simulators that generate microwave representations of the operational scenarios that were agreed upon with the customer when the system specifications were drafted.

  Similarly, just as it is possible to feed real numerical data into the model, data recorded in flight from onboard sensors can be injected into the system's digital processing units.

  The last example is about controlling antenna radiation and decoupling between antennas.

  To meet this requirement and also to avoid long and costly in-flight evaluation programs to gauge jamming or jamming detection performance, Thomson-CSF set up a special platform at its Le Mengam site near Brest in Brittany.

One of the main uses of this platform has been to validate the simulation tools mentioned earlier, including SARGASSES. But for customers, it is also a less uncertain and more comprehensive benchmark for system acceptance than in-flight testing can be.

Modeling techniques now offer such high quality and reliability that Le Mengam platform is only used part of the time. It is available to any company or organization that wishes to use it and that can work there totally independently.

5. MONITORING AND DEMONSTRATING OPERATIONAL PERFORMANCE ON THE GROUND (CHART 22)

The purpose of the tools we have looked at so far is basically technical, even if we correlate the technical measurements with clearly defined operational objectives whenever this is possible.

However, the operational performance of an onboard system cannot be fully and convincingly monitored and demonstrated on the ground for the customer, unless the dynamic behaviour of the aircraft can be taken into account.

This is why Thomson-CSF set up a dynamic testing centre for onboard equipment and systems in the facility set aside for this purpose by the French defence procurement agency at the Brétigny test range near Paris.

The centre has an anechoic chamber, a mobile platform and a radiating wall that can simulate transmitters in a broad range of frequencies, as well as radar targets. The Brétigny centre is presented in the video.

This centre has been extremely valuable and made substantial savings in test flight hours when evaluating multi-target combat modes for fire control radars. It can also be used to evaluate aircraft self-protection systems, and an optronic source module is currently being designed.

These examples have shown what can be done on the ground to overcome risks on airborne programs and to keep in-flight development testing to a strict minimum.

(VIDEO ON METRO, LE MENGAM, BRETIGNY)

This presentation (chart 23) has covered the main stages in the industrial process of integrating an onboard system. The real life of the system, its operational life, begins at the end of this process.

The same tools as were used to define the system will now help to train operators to program the system (threat identification and jamming/deception libraries, for example).

They will also be used throughout the system life cycle to interpret new situations and propose improvements where possible.

This permanent dialogue with the people who use the system that is finally delivered is extremely important. It not only enables us to validate the whole of the industrial process by seeing what happens in real operational conditions—the only conditions that ultimately matter—but also makes us better prepared to cope with future systems.

Substantial industrial resources are therefore needed to define, integrate and support onboard systems, and those resources need to be utilized as fully as possible and developed on a permanent basis. These industrial assets in turn rely on the even more substantial resources of government research and testing establishments.

Until now, France has managed to set up most of these resources itself. During successive programs, close ties have been forged between manufacturers of airframes, engines and electronic systems, and between industries, government bodies and customers.

Today, however, reductions in defence spending and the increasing complexity and cost of these systems mean that major European players need to work even more closely together and to pool the resources that they have at their disposal (chart 24).

Some concrete examples can be given :

a) The AMSAR program of future airborne program between Thomson in France, GEC in the United Kingdom and Dasa in Germany is an example of how successful this kind of cooperation can be. It was successful because resources and experience were shared effectively and duplication of efforts was avoided. Above all, it was successful because of the quality of the relationships that grew up between the different teams involved.

b) Another example is within reach of the Europeans and concerns system integration more directly. This is the modular avionics concept for combat aircraft. In this area, the United Kingdom, Germany and France have defined their objectives and configured their respective industries. In France, a formal 50-50 partnership (GIE) has been set up between Dassault Aviation and Thomson-CSF to conduct a program of this kind with European partners.

c) The digital processing market changes very quickly, and it is now possible to adopt a very open approach to architectures, based on the use of commercial off-the-shelf software and aiming above all at achieving greater reusability of application software as hardware performance improves.

d) THOMSON and ELETTRONICA in Italy have decided to cooperate, THOMSON having taken a 33% share in the capital of ELETTRONICA, so far . This strategic alliance definitely stregthens the two companies' leadership in the domain of Electronic Warfare. Not only can we address a broader market, which is the commercial and marketing asset of this alliance, but also can we specialize each company in its better skill for such line of products, which is the industrial and technical asset of this alliance.

* *

For decades of experience in Defence systems and thanks to the subsequent tools which have just been presented in this lecture, THOMSON has combined the need of high level of performance with affordable costs, both for our customers' satisfaction.

Now, the times have come when we also have as smartly as possible to combine the strengths of European companies with ours. We have begun to follow this strategic path, still with the final objective of our customers' satisfaction, but also of the survival of our high skill and high added-value activity, hopefully.

Finally, strategic management of the cost issue is not less than to address this fascinating spectrum of our companies' skill, starting from the deepest scientific and technical knowledge to the combination of know-how and cultural behaviours of partner companies, having to cooperate in a closer and closer way.

-- Septembre 1997 --

THOMSON-CSF Radar & Contre-Mesures
AREAS OF ACTIVITIES

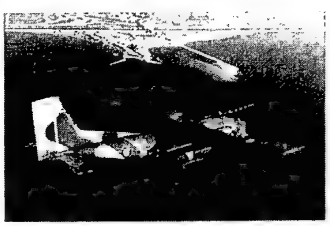
- SINCE MORE THAN 30 YEARS, A MAJOR COMPANY IN THE DOMAINS OF :
  - AIRBORNE RADARS
  - ELECTRONIC WARFARE & INTELLIGENCE
  - AIRBORNE SYSTEMS
- IN SERVICE OF FRENCH FORCES AND OF MORE THAN 40 COUNTRIES WORLDWIDE

THOMSON-CSF
RADARS & CONTRE-MESURES

81472

CHART 1

Airborne self - protection systems



MSPS
SUPER-ETENDARD - C160

EWS
NH 90 (TTH)

TWE
TIGRE

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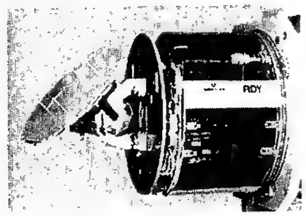
RADARS & CONTRE-MESURES

81292

CHART 2

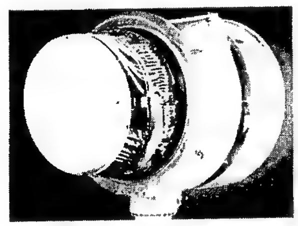
Airborne Combat Radar and self - protection Systems

ICMS
MIRAGE 2000



RDY

SPECTRA
RAFALE



RBE2

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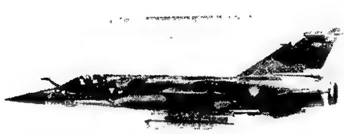
CHART 3

ELINT Systems



F1 CR

F4 EJ

F16

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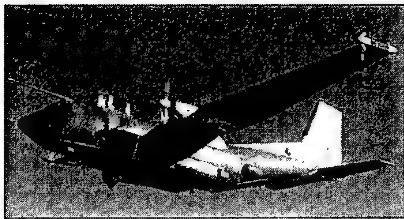
CHART 4

SIGINT Systems



C 160 GABRIEL

DC 8 SARIGUE

SPACE APPLICATION

81474

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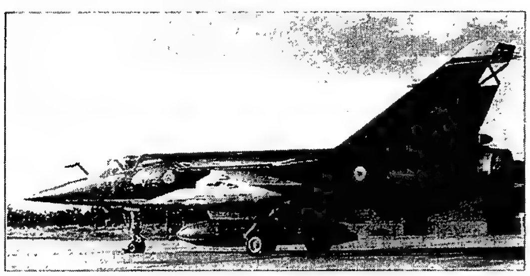
CHART 5

Airborne programs and systems



MIRAGE F1 - SPAIN

AMASCOS

81290

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CHART 6

Airborne System Integration

CONDITIONS TO THE SUCCESS

- PERFECT UNDERSTANDING OF THE CUSTOMER'S REQUIREMENTS AND EXPECTATIONS
- AGREEMENT ON THE SOLUTIONS CHOSEN TO MATCH THE REQUIREMENT
- AGREEMENT ON THE TEST AND EVALUATION PROCESS
- CONTINUOUS TIGHT CONTROL OF THE RISKS DURING THE DEVELOPMENT PHASE OF THE SYSTEM
- SUPPORT OF THE CUSTOMER ALL ALONG THE OPERATIONAL LIFE OF THE SYSTEM

RADARS & CONTRE-MESURES

69405

CHART 7

Airborne System Integration

METHODOLOGY AND ADAPTED TOOLS FOR

- A CUSTOMER REQUIREMENT UNDERSTANDING
- B RISK MINIMIZATION
- C TECHNICAL PERFORMANCE VALIDATION
- D OPERATIONAL PERFORMANCE DEMONSTRATION

RADARS & CONTRE-MESURES

69405

CHART 8

STEP 1 - Understanding the requirement

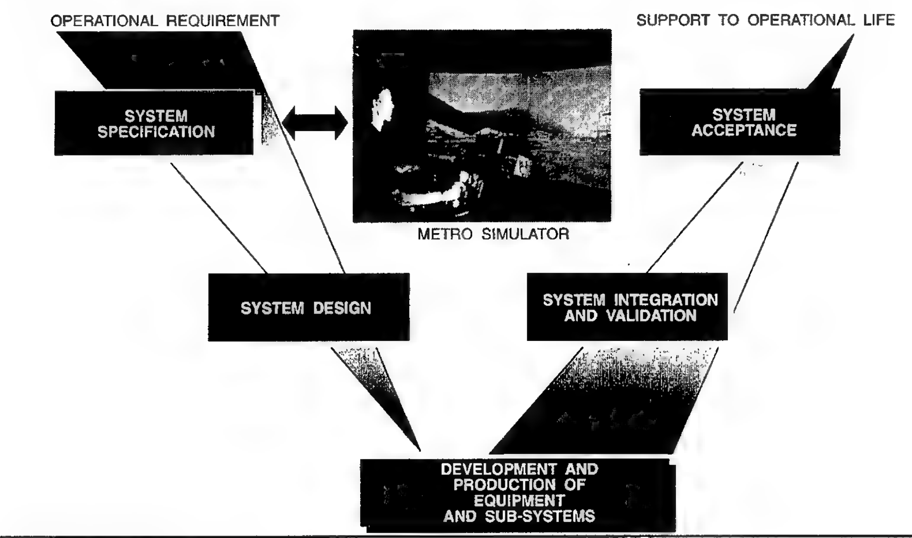

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CHART 9

STEP 2 - System Design

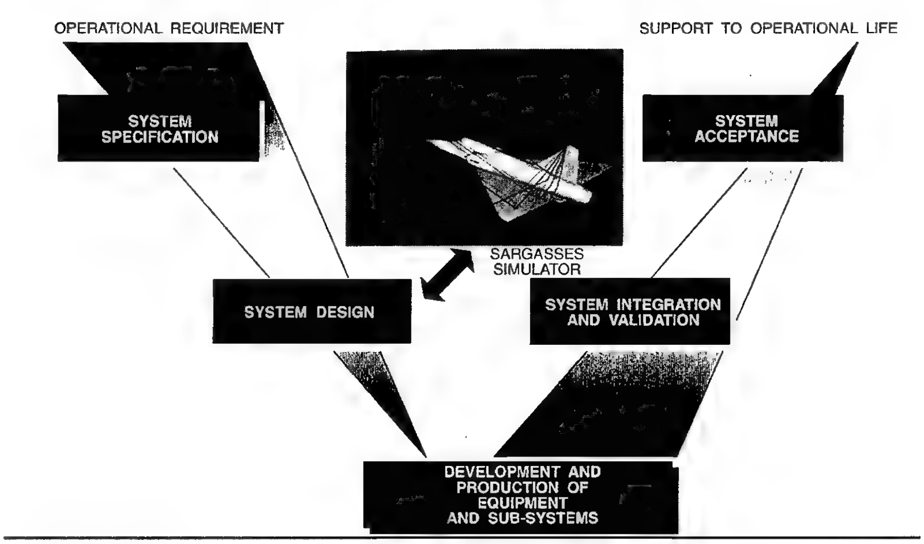

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CHART 10

STEP 3 - Technical performance validation

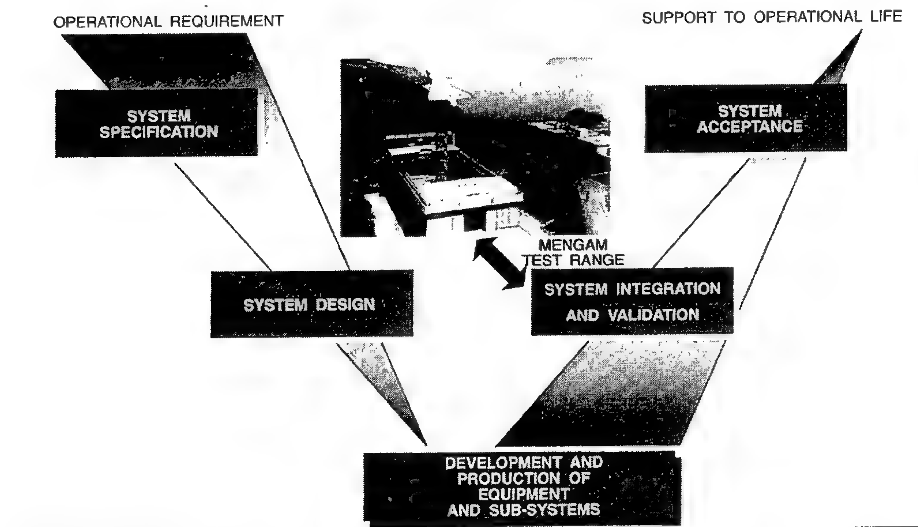

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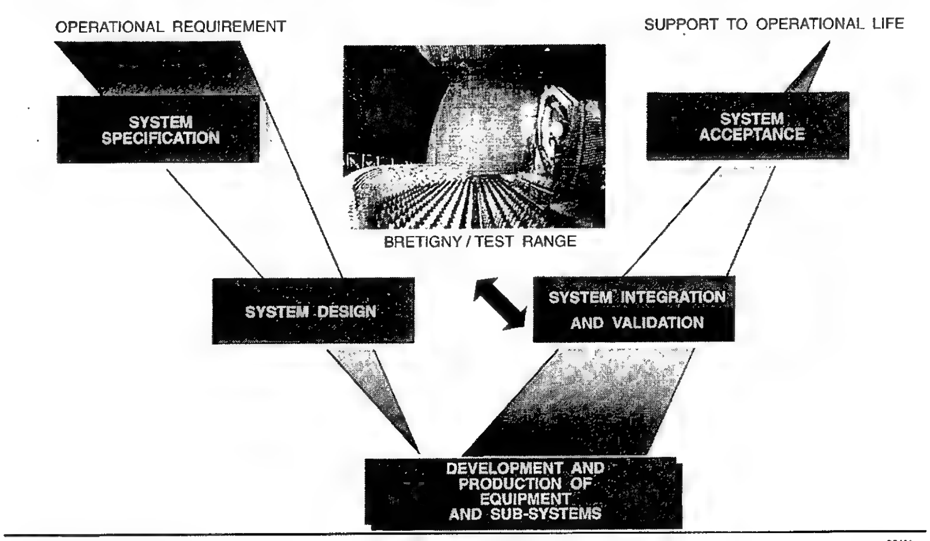
CHART 11

STEP 4 - Ground performance validation



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69411

CHART 12

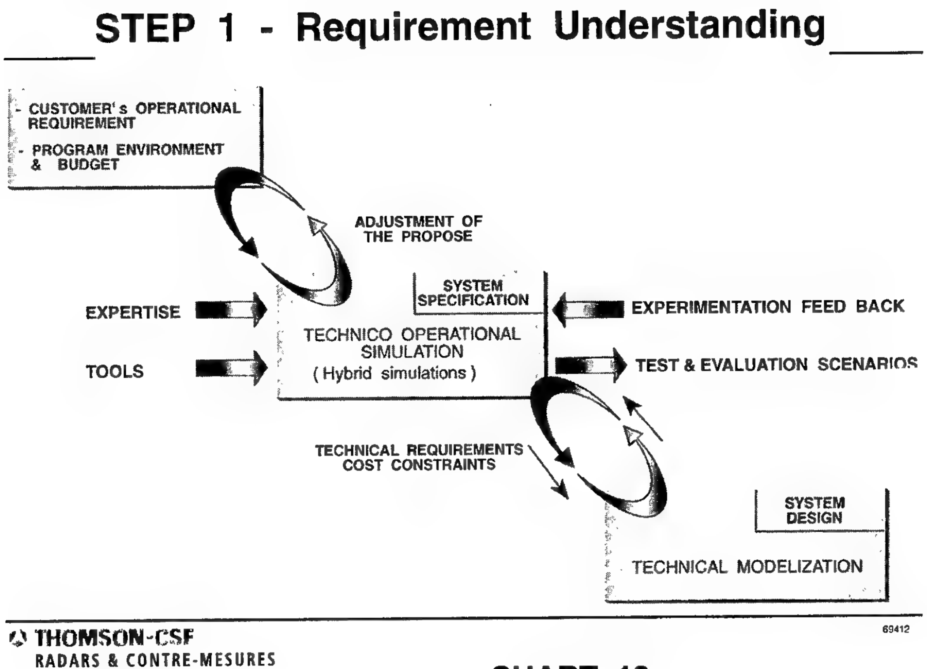


CHART 13

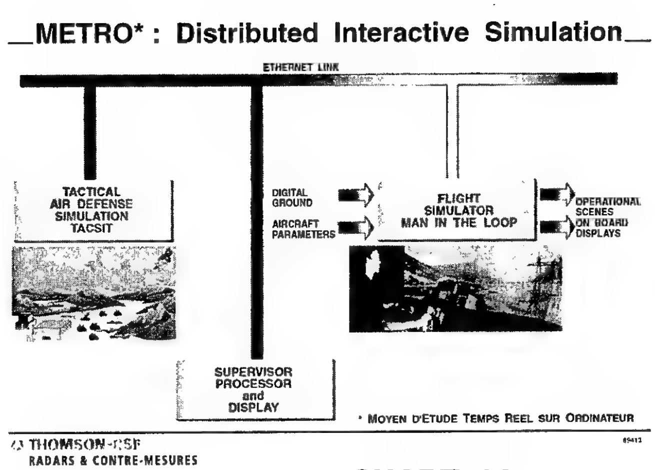
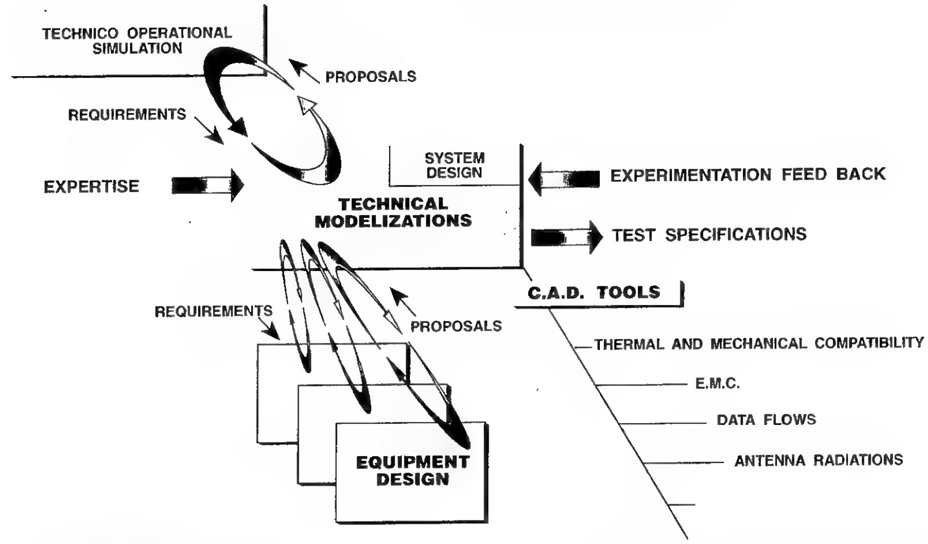


CHART 14

STEP 2 - Risk evaluation



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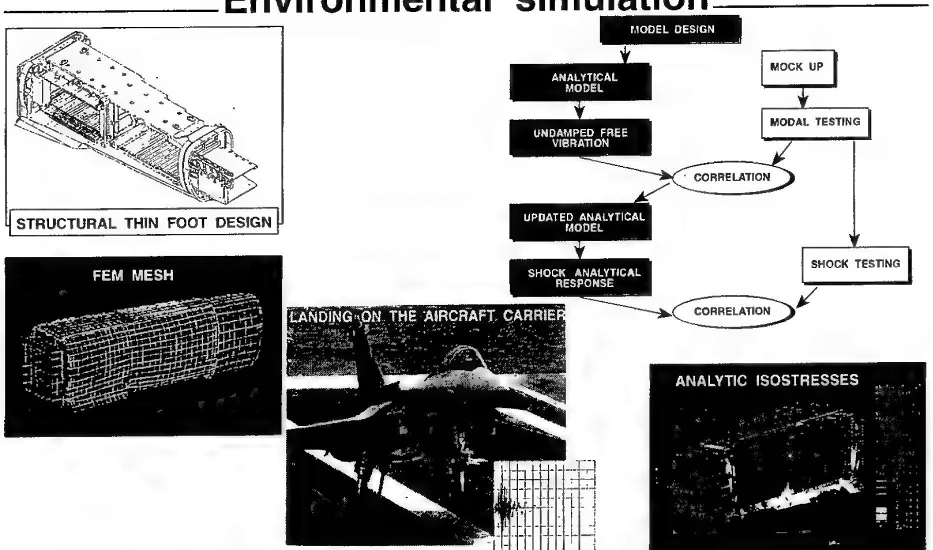
69613

CHART 15

Environmental simulation



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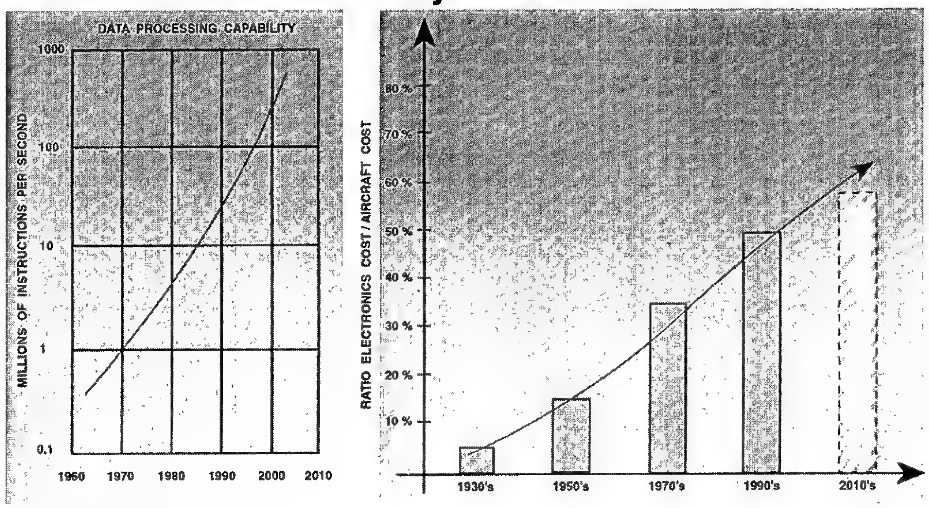
69617

CHART 16

Evolution of Electronics Part in Aircraft Systems



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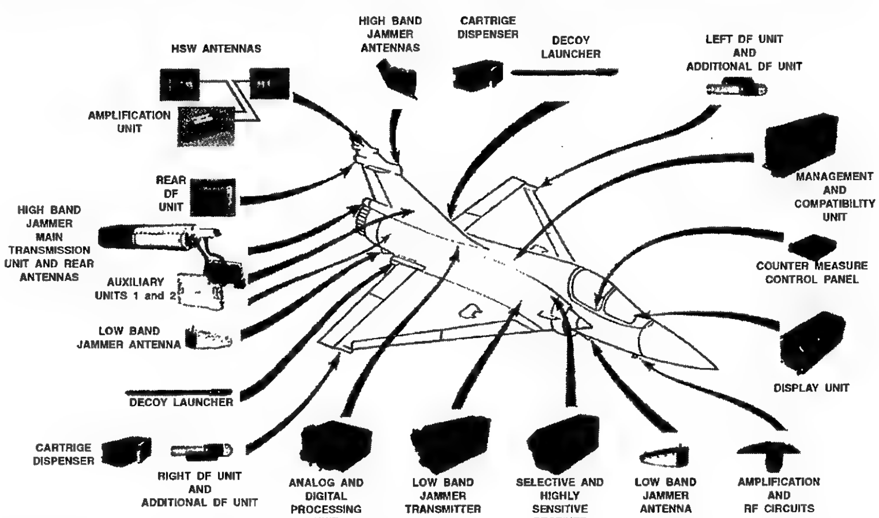
81501

CHART 17

ICMS 2000



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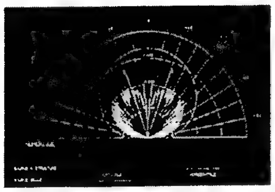
RADARS & CONTRE-MESURES

69614

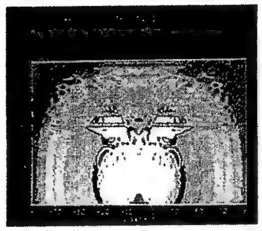
CHART 18

SARGASSES

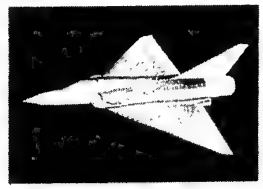
INSTALLED ANTENNA PERFORMANCE



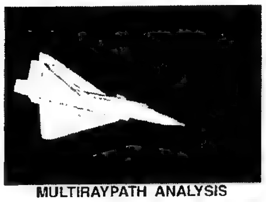
RADIATION PATTERN
(Constant Elevation or Bearing)



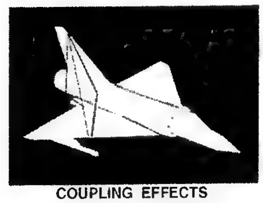
RADIATION PATTERN
(Elevation and Bearing)



A / C STRUCTURE
INFLUENCE ZONES



MULTIRAYPATH ANALYSIS



COUPLING EFFECTS
BETWEEN ANTENNAS

81977

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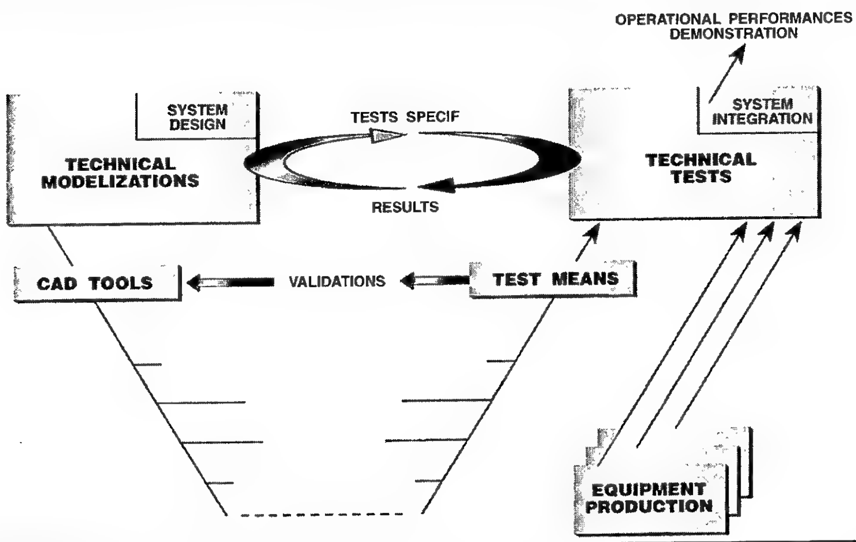
CHART 19

STEP 3 Technical Performance Validation



69416

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RADARS & CONTRE-MESURES

CHART 20

ICMS test bench

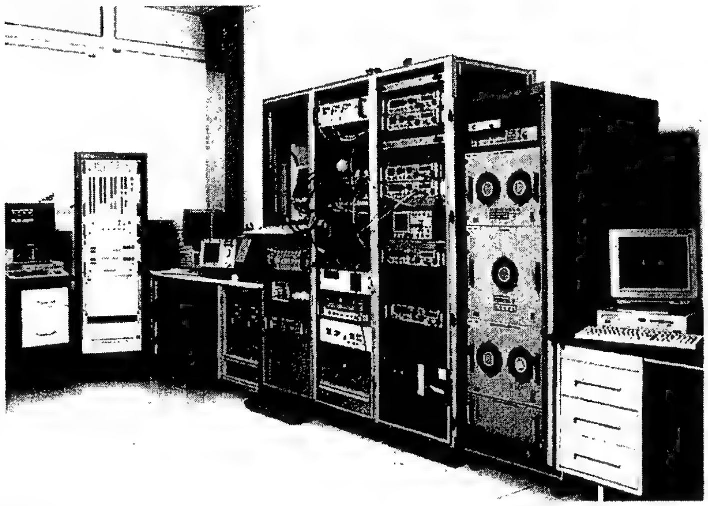

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CHART 21

STEP 4 : on ground operational performance demonstration

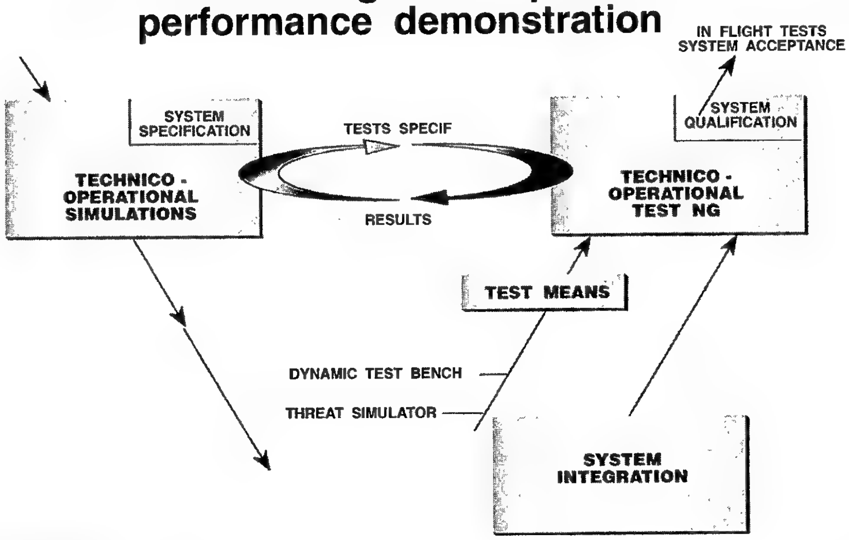

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CHART 22

Typical System Life Cycle

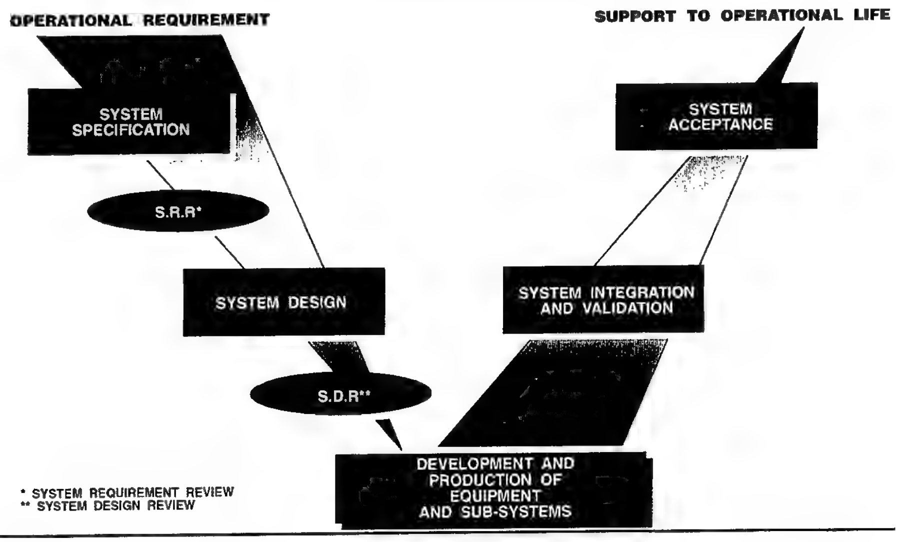

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CHART 23

Airborne System Integration

- A MATTER OF COOPERATIONS
  - COOPERATION WITH GOVERNMENT ESTABLISHMENTS
  - COOPERATION WITH AIRCRAFT MANUFACTURERS
  - COOPERATION WITH ELECTRONICS COMPANIES
- BESIDES TECHNICAL AND PROGRAM MANAGEMENT SKILL, COSTS WILL ALSO BE DRIVEN BY THE ABILITY TO COOPERATE WITH PARTNERS

81475

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CHART 24

THE AERMACCHI YAK/AEM-130 AND AT-2000 DESIGN OBJECTIVES: A TOPIC IN THE SUBSONIC VS.SUPERSONIC TRAINING TRADE-OFF

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21040 Venegono Superiore (Varese), Italy

SUMMARY

A modern trainer should be designed in accordance with the needs imposed by the entry into service of new and more capable operational aircraft. The trainers currently in service were designed, at best, with late 60's generation fighters in mind.
The introduction of a modern trainer into service will allow substantial savings, over their life-cycle, with respect to the existing advanced trainers, even if updated with state-of-the-art avionic systems.
This paper deals with the cost-effectiveness of selecting a subsonic or a supersonic configuration as a baseline.
The result of a quantitative evaluation, carried on a representative training scenario, shows that the higher costs of a supersonic configuration will not be paid by the reduction in training costs, and that the optimal baseline is still a subsonic trainer, designed to be representative as much as possible of the modern combat aircraft.

1. Introduction

Aermacchi, established in 1913, is today one of the oldest aerospace companies. After merging with SIAI Marchetti at the end of 1996, Aermacchi has today 1650 employees and sales near to 200M$. The main activities spread from commercial aerostructures (Do-328, Falcon2000, engine nacelles), to cooperations in military programs (Tornado, EF-2000, AM-X); the company core business is however focused on training aircraft.
Today Aermacchi training products range from the SF-260 screener/initial trainer through the M-290TP Redigo basic turboprop and the S-211 basic jet trainer up to the MB-339FD advanced/lead-in trainer.
These aircraft (and their MB-326 predecessor) have been sold in over 2000 units to 38 worldwide customers.

2. New trainers development in Aermacchi

Since 1985 Aermacchi started planning the introduction in its product range of a new, very advanced training aircraft. The initial studies covered a wide range of requirements, but soon the focus was shifted to a high transonic configuration, with limited supersonic capabilities, able to cover both the primary role of advanced/fighter-lead-in training and a secondary role as a lightweight fighter.
From 1985 to 1995 Aermacchi invested around 500,000 engineering hours studying 20 different configurations (canard, aft-tail, single and twin engine, dry and augmented propulsion), introducing in the design the result of 5000 hours of wind tunnel testing and of 3000 hours of simulation.
The AT-2000 preliminary design envisaged a

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full-authority FBW aircraft featuring a variable camber wing, coupled with a forebody / strakes / empennage design able to provide good transonic characteristics, coupled with a linear and predictable behaviour well over 35 degrees angle of attack.
During these studies Aermacchi was joined initially by Dornier, then by DASA LM.
The work on the AT-2000 ended in late 1995, freezing the final configuration.

In 1992 Aermacchi started evaluating what was then known as the YAK-UTS, a new trainer which was under initial development at the Yakovlev Design Bureau in Moscow. The YAK-UTS design had many common points with the AT-2000, being a very advanced trainer, capable of medium/high angles of attack, featuring a moderate aspect ratio wing with variable camber, large strakes, chined forebody.
Due to a firm requirement from the Russian Air Force, the aircraft was based on a twin-engine configuration, being the engine initially selected the AI-25.
Given the high similarity of technical characteristics between the YAK-UTS and the AT-2000, a cooperation agreement with the YAK Design Buro was signed in 1993, which allowed Aermacchi to take part in the conceptual and preliminary design, in the development and production and in sales of the aircraft.
Up to mid 1997, Aermacchi performed around 280,000 engineering hours, working on redefinition of the configuration, aerodynamics (with 2000 hours of wind tunnel testing), FBW design (with 2000 hours of test rig simulations), and taking part to the flight test activities being performed on a DEM-VAL aircraft build by Yakovlev which flew in April,1996. This demonstrator was based at the Aermacchi facilities during July 1997 for a short test campaign focused on performance validation and FBW assessment.
As a result of these activities the YAK-UTS configuration was widely modified to cope with the general and detailed requirements defined by Aermacchi, becoming the YAK/AEM-130, a sensibly smaller and lighter aircraft powered by two more powerful DV-2S engines.
The current planning envisages that the first YAK/AEM-130 prototype aircraft will fly end 1998/early 1999, with a first batch of ten aircraft in service with the Russian Air Force by year 2000. The prototype of the international version, which will differ from the russian aircraft mainly in the avionic system, will fly in early 2000, with start of deliveries possible from year 2002.

3. New trainer requirements

The AT-2000 before, and the YAK/AEM-130 after, have been designed around requirements derived from the training needs foreseen for the next future.
New combat aircraft types have been introduced into front line service, featuring operational capabilities greatly increased with respect to the previous generation of fighters and attack aircraft.

The new combat vehicles feature large improvements in energy/manoeuvrability, expecially in the transonic arena, with turn rates and specific excess power largely increased when compared to last generation fighters (Fig.1) . High angle of attack capability, meaning the ability to effectively manoeuvre above 30-35 degrees, is now featured by many of the new types, and this capability is brought to its extreme when thrust vectoring is adopted (Fig. 2).

The functional capabilities are multiplied by new, extremely powerful and light processors and sensors, which have allowed the fielding of true multi-role aircraft. New weapons have taken advantage of sensors and processors miniaturization, and new tactics have been developed to exploit them. The appearance of lightweight liquid crystal displays has dramatically changed the cockpit layout, allowing the pilot to concentrate on mission management, instead of looking at his aicraft's round dials.

This large increase of performance/capabilities in combat types is already posing new demanding requirements to the Air Forces training systems which, for the majority, are still operating trainers which were at best designed for the F-4 class fighters.
This results is an increase of flight hours needed to bring a pilot to the combat readiness in the new types, but due to the trainers lack of capabilities, most of these hours have to be

performed on the combat aircraft itself.
The cost of training up to combat readiness is therefore increased, posing budgettary problems to already strained Air Forces economies.

Any new trainer shall therefore be designed to extend as much as needed the skill of the pupil at the end of his syllabus at the flying school, thereby reducing the number of flight hours required on the new combat aircraft before combat readiness (Fig.3).

The main requirements resulting from the above analysis are:

- Good high end characteristics, in terms of energy, acceleration and speed.
- A significant low altitude speed persistance, both in terms of gust ride and fuel flow.
- Excellent manoeuvrability (sustained load factor/turn rates) at typical manoeuvre altitudes and speeds.
- Fast to climb to training altitude and to accelerate to manoeuvre speeds.
- Representative of the combat aircraft behaviour at medium/high angles of attack (30-40°).

Being however a trainer aircraft, some requirements must be added to allow an easy transition from lower types, such as basic turboprops or even high power piston trainers:

- Low terminal speeds, expecially at final approach.
- Excellent low speed characteristics.
- Forgiving handling.
- Performance and handling should be progressively increased to match the pupil capabilities, up to the point of matching the operational aircraft flying qualities (in-flight simulation).

From the man-machine interface point of view, a new trainer must reproduce the cockpit environment of modern combat aircraft; however also the displayed information must be similar in qualitative and, if possible economically, quantitative terms. Navigation and weapon delivery computing functions shall therefore be as close as possible to those of an operational aircraft, while targeting sensors (RADAR, FLIR; IRST,...), which are still outside the cost range for a trainer, will be simulated, as far as possible (embedded training).

The requirements for a new trainer shall also take into account the need, from many Air Forces, of providing limited fighting capabilities in a secondary role; the new trainer shall thence be capable of carrying at least 6000 lb of weapons, with a limited degradation in performance, and shall be able to operate with the said loads from short runways and in hot/high conditions.
All these requirements can be quantitatively expressed by saying that the the "TRAINING EFFECTIVENESS" of the aircraft should reach a given figure, and that the increase in training effectiveness, with respect to existing trainers, should be proportional to the increase of operational capabilities witnessed in the operational aircraft (Fig.4).

4. Training effectiveness measurement

In the last 20 years, Aermacchi has constantly worked to a quantitative model able to measure the effectiveness of a trainer aircraft. The early models, known as "Bazzocchi method" after the former General Manager of Aermacchi, have been updated to take into account new characteristics, tactics and functional capabilities.
The basis of this method is the quantitative evaluation of the "training effectiveness", which is defined as the pupil skill increase per flight hour (Fig.5).

It is assumed that the training effectiveness is a function of the trainer performance, functional capabilities, flight envelope (in an extended acception), and type of man-machine interface. By giving quantitative values to each parameter (load factors, angle of attack, range, number of flight management functions, number of weapon aiming modes, typical speeds, turn rates ...), a quantitative evaluation of the training effectiveness is obtained.

It can be shown that a good statistical correlation exists between the so defined teaching effectiveness and the number of flight hours flown in a given aircraft before the saturation of its capabilities (Fig. 6), when it is convenient to graduate the pupil to a more capable aircraft; the saturation level for the combat aircraft is the "combat readiness" status for the operational pilot.
Knowing the training effectiveness of a

succession of trainers and of the "target" combat aircraft is therefore possible to define an "optimum" syllabus (in terms of flight hours on each aircraft, including the target), where each trainer is used up to its saturation point and no more.

The model allows also to compute the Life-Cycle Cost per flying hour of all the aircraft involved in the training process.
The life-cycle cost analysis is based on a parametric model which computes separately the development cost, the fly-away cost, the procurement cost and the operation and support costs. The parametric model is constantly trimmed on actual data, whenever these can be found reliable.

It is therefore possible to couple the teaching effectiveness of each aircraft with its life-cycle cost per f.h. (fig. 7), and to compute the cost of the "optimum syllabus" previously defined, up to the final cost of a combat ready pilot on a given operational aircraft (fig.8).
This cost can take into account also the overhead costs and the extra costs due to trainee pilots "washout".
It is now possible to compute the cost of training of a combat ready pilot, with different hypotheses on the advanced trainer used in the syllabus, and to compare the final cost using a subsonic (I.E. the YAK/AEM-130) or supersonic (I.E. the AT-2000) trainer.

5. Trainers design trade-off: subsonic vs. supersonic

The design point characteristics of the YAK/AEM-130 and of the AT-2000 are compared in fig. 9. It can be seen that the take-off mass is roughly the same, but the AT-2000 point performance is higher, providing real supersonic capabilities, even at the expense of a reduction in range and endurance.

The training effectiveness of these new trainers can now be compared to an existing advanced trainer.
For comparison purposes, the MB-339CD has been chosen as the baseline. This model, recently acquired by the italian Air Force, is the newest member of the '39 family: it is fitted with a fully integrated digital avionic system, which includes inertial (RLG) / GPS navigation, HUD with AA/AG weapon aiming modes, three LCD MFD's in each cockpit.
Fig.10 shows that both the subsonic and supersonic configurations provide a significant leap forward in terms of training effectiveness with respect to an existing advanced trainer,even if fitted with a state-of-the-art avionic system. The final skill of the pilot at the end of the training cycle on the advanced trainer can be doubled, by increasing the real number of flown hours by a moderate quantity.

However, the cost of the new trainers is higher than that of the existing ones, and this is expecially true for the AT-2000, whose development costs are nearly four times those of the existing baseline (fig. 11).
The development and procurement costs of the YAK/AEM-130 are further reduced by the cooperative nature of the program.

The final cost-effectiveness of both aircraft is shown in fig. 12: while the YAK/AEM-130 and the AT-2000 are both a substantial leap forward in terms of cost-effectiveness, the first still shows a small advantage.

The cost of training a combat-ready pilot on different types is shown in fig. 13.
The supersonic trainer will allow a significant cost reduction in the training process for EF-2000 and Tornado pilots, but will actually increase the cost of training an attack/close air support AM-X pilot, since it will not be possible to exploit the aircraft up to its full potential (this is partly true also for the Tornado track).
The subsonic trainer will allow significant savings on all types, but more so in the attack/CAS track and in the Tornado track, where its capabilities will be fully exploited at a much lower cost than that of the supersonic aircraft.

If we take into account a representative distribution of "fighter track" pilots between the types, we can compute the yearly training costs of an Air Force: it can be seen that the introduction of a modern trainer can allow significant savings, but more so for the more economic subsonic advanced trainer (fig.14).

6. Conclusions

A modern trainer should be designed in accordance with the needs imposed by the entry into service of new and more capable operational aircraft. The trainers currently in service were designed, at best, with the late 60's fighters in mind.

The introduction of a modern trainer into service will allow substantial savings, over their life-cycle, with respect to the existing advanced trainers, even if updated with state-of-the-art avionic systems.

A modern supersonic trainer will allow a substantial reduction of the cost of training a combat-ready pilot for the front-line aircraft (EF2000, Rafale, F-22A, F/A-18E class),but training costs for all the other pilots which need advanced/lead-in training (attack, strike, recce, ECR, ...) will be less favourably affected.

A modern subsonic/transonic trainer will achieve less substantial cost reduction for the training of front-line fighter pilots, but will allow greater savings in the other tracks.

Both configuration must however be designed for high AoAs, to be representative of the behaviour of modern combat aircraft even during unusual manoeuvres.

The need for real supersonic training is therefore limited and, in and by itself, is not enough to pay for the vastly higher development costs required. Also the procurement and O&S costs of the supersonic trainer will be higher.

The requirement for a secondary role capability for the advanced trainer can push towards a supersonic configuration, expecially if "point defence" roles would be envisaged. It must however be recognized that these capabilities will be limited by the aircraft maximum economical size as a trainer: in particular the number and kind of weapons that can be integrated on a small aircraft will be reduced, as will be the payload/range characteristics of any advanced trainer, when compared with those of an F-16C class fighter.

In the last years the aerospace industry has often pursued the T-38/F-5 legacy dream, but the expected market success has still to materialize.

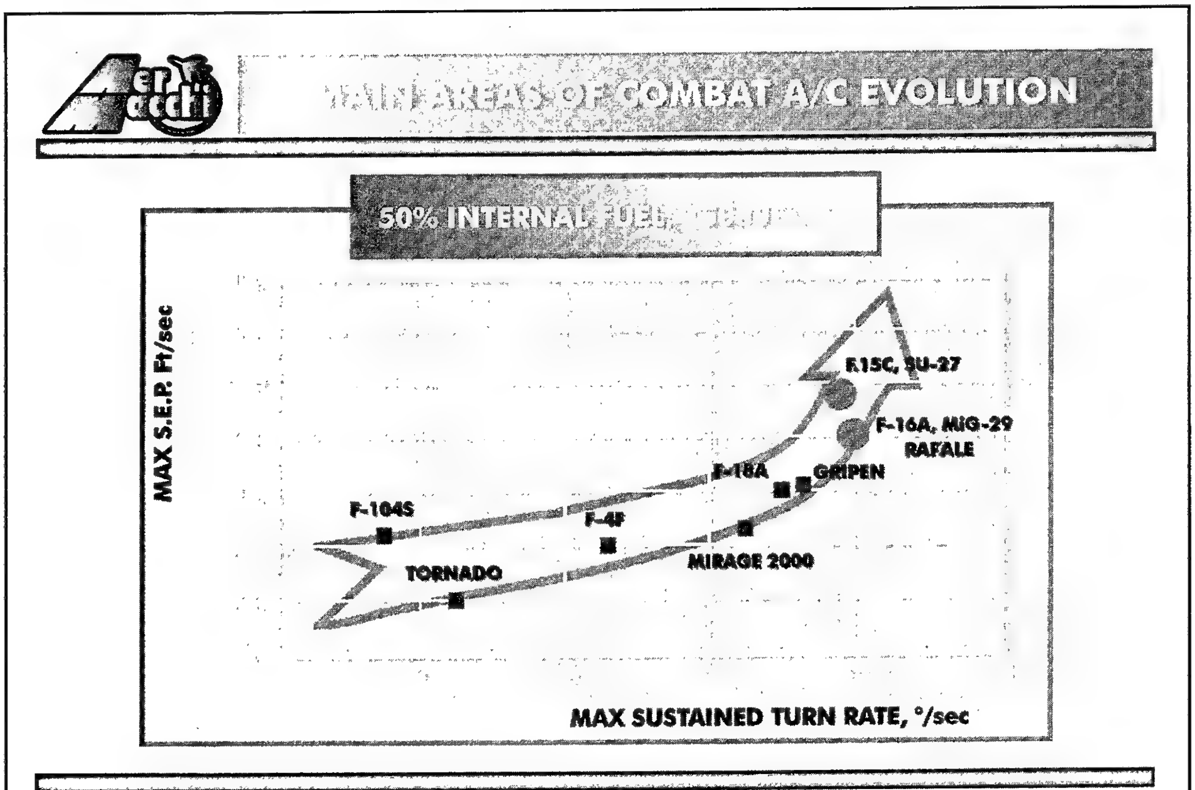
AREAS OF COMBAT A/C EVOLUTION
50% INTERNAL FUEL
MAX S.E.P. Ft/sec
F15C, SU-27
F-16A, MIG-29
RAFALE
F-18A
GRIPEN
F-104S
F-4F
MIRAGE 2000
TORNADO
MAX SUSTAINED TURN RATE, °/sec

fig 1

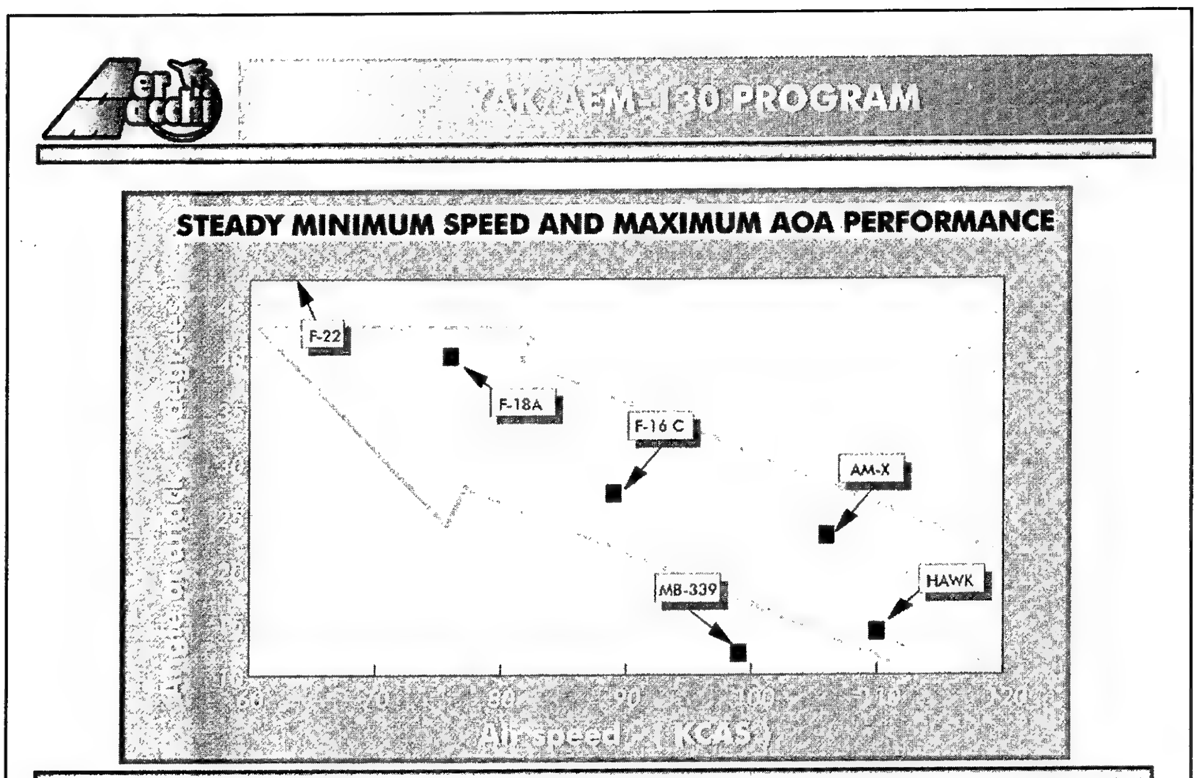
PROGRAM
STEADY MINIMUM SPEED AND MAXIMUM AOA PERFORMANCE
F-22
F-18A
F-16 C
AM-X
MB-339
HAWK

fig 2

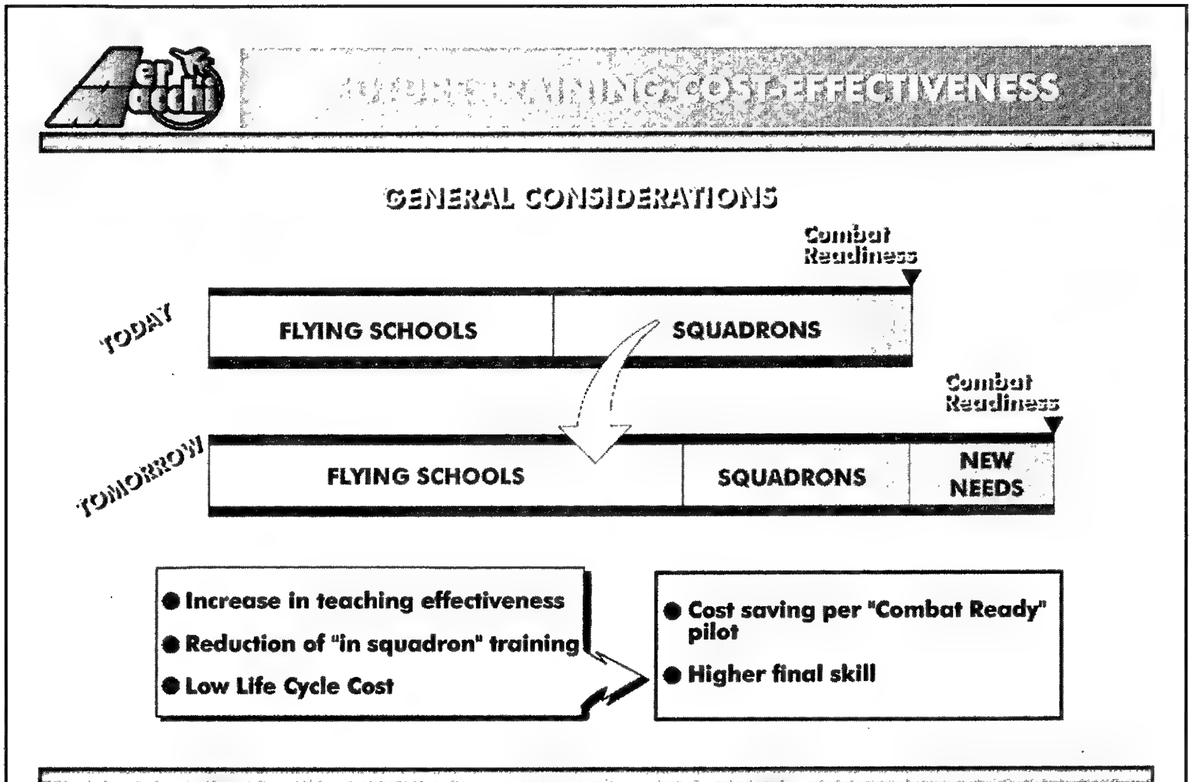
COST-EFFECTIVENESS
GENERAL CONSIDERATIONS
Combat Readiness
TODAY
FLYING SCHOOLS
SQUADRONS
Combat Readiness
TOMORROW
FLYING SCHOOLS
SQUADRONS
NEW NEEDS
Increase in teaching effectiveness
Reduction of "in squadron" training
Low Life Cycle Cost
Cost saving per "Combat Ready" pilot
Higher final skill

fig 3

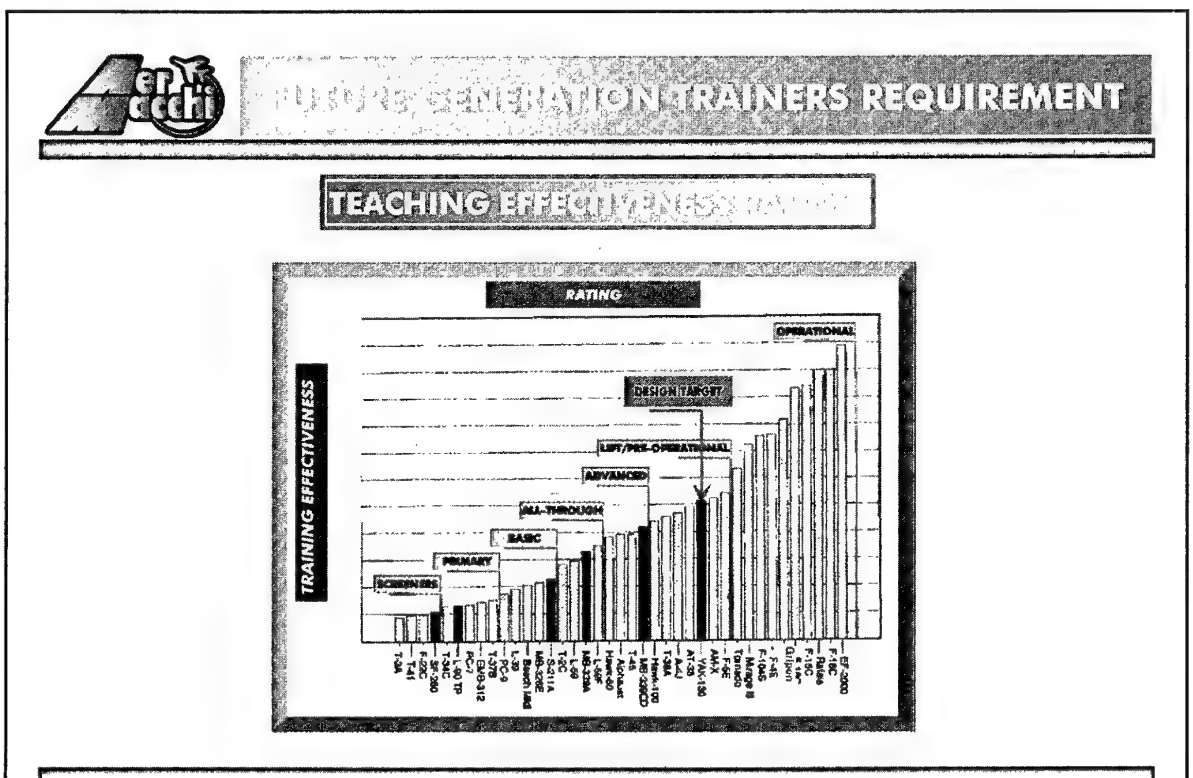
GENERATION TRAINERS REQUIREMENT
TEACHING EFFECTIVENESS
RATING
TRAINING EFFECTIVENESS
OPERATIONAL
DESIGN TARGET
LIFT/PRE-OPERATIONAL
ADVANCED
ALL-THROUGH
BASIC
PRIMARY
SCREENERS

fig 4

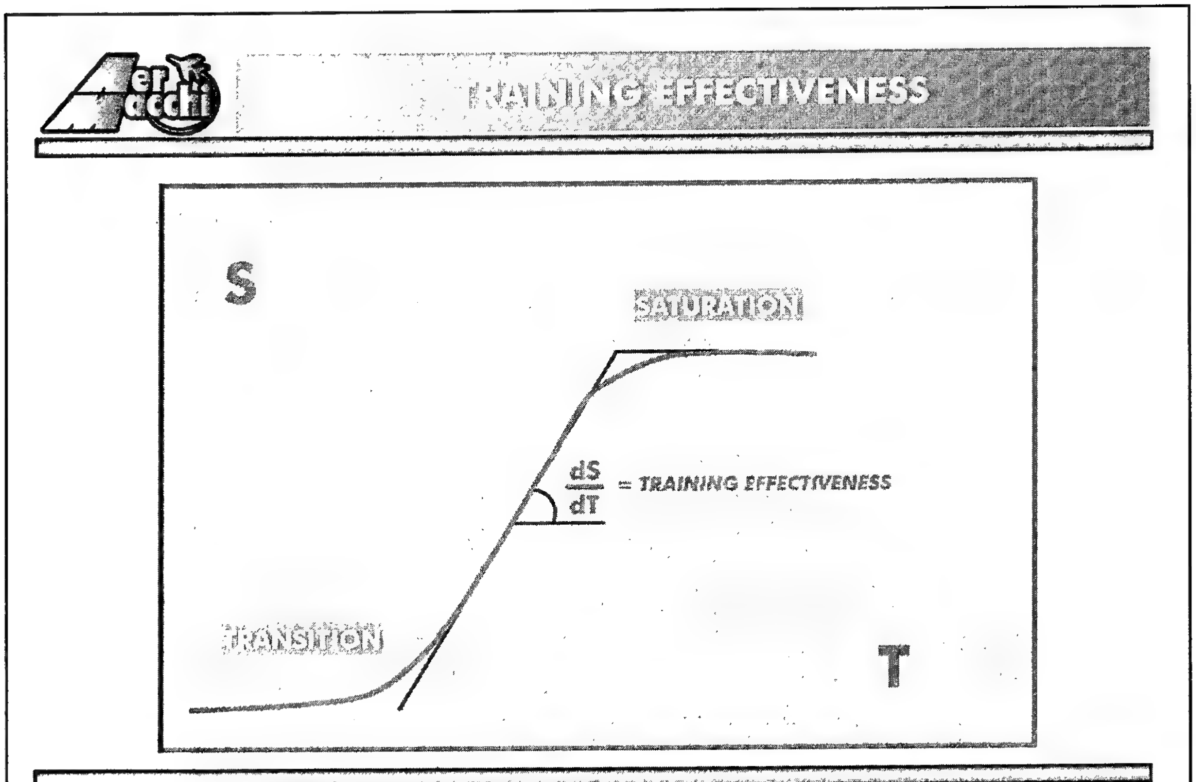
TRAINING EFFECTIVENESS
S
SATURATION
$\frac{dS}{dT}$ = TRAINING EFFECTIVENESS
TRANSITION
T

fig 5

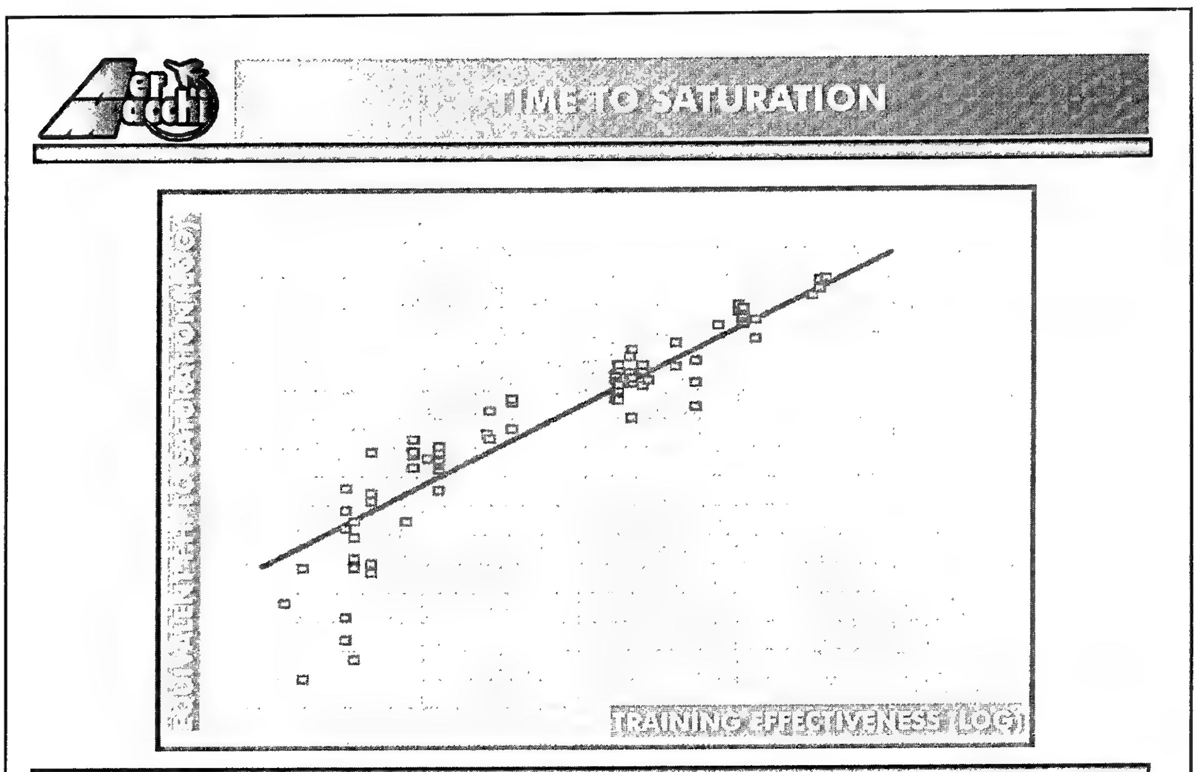
TIME TO SATURATION
EQUIVALENT TIME TO SATURATION (LOG)
TRAINING EFFECTIVENESS (LOG)

fig 6

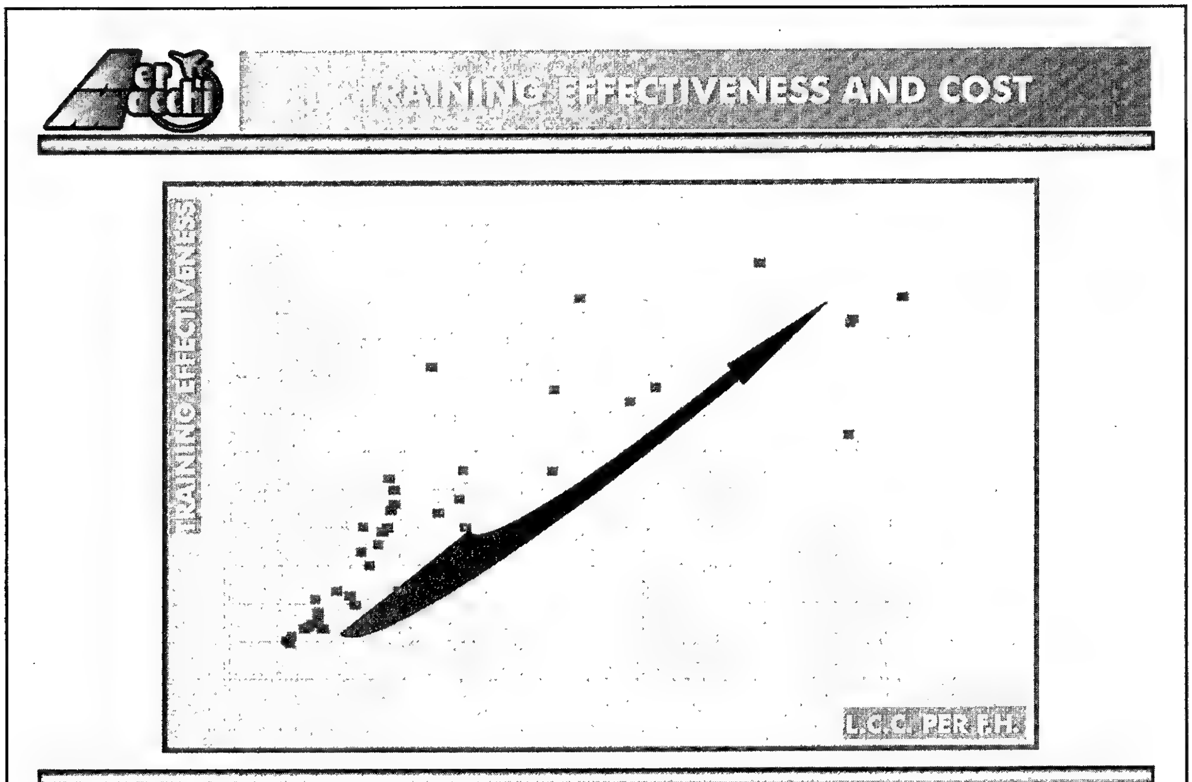
TRAINING EFFECTIVENESS AND COST
TRAINING EFFECTIVENESS
L.C.C. PER F.H.

fig 7

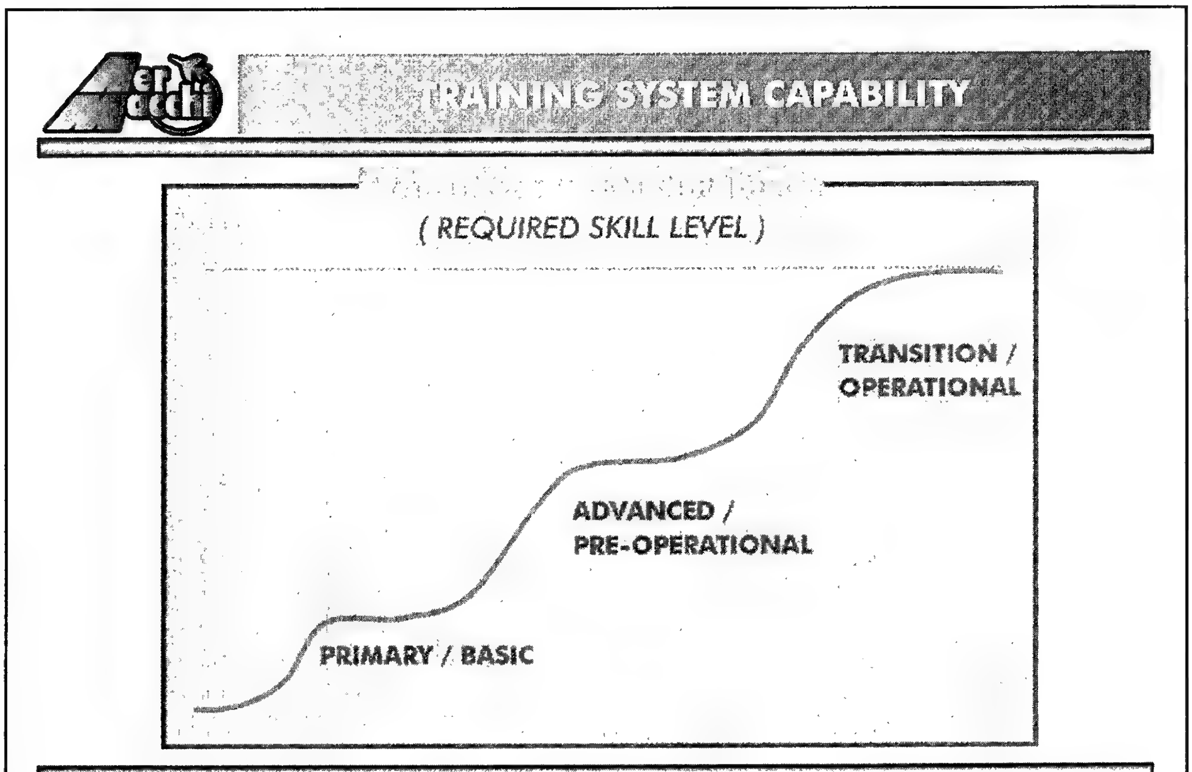
TRAINING SYSTEM CAPABILITY
(REQUIRED SKILL LEVEL)
TRANSITION / OPERATIONAL
ADVANCED / PRE-OPERATIONAL
PRIMARY / BASIC

fig 8

COMPARISON

	YAK/AEM-130	AT-2000
MAX LEVEL SPEED, SL	*540Kts*	*650Kts*
SUST. LOAD FACTOR, 15KFt	5g(@M=.8)	7g(@M=.85)
MAX S.E.P., 15KFt	*230 Ft/s*	*550 Ft/s*
MAX MACH	*0,92*	*1,45*
TRANSONIC ACCELERATION	-	*50"*
APPROACH SPEED	*100Kts*	*120Kts*
RANGE, N.M.	*1200 NM*	*1000 NM*
TAKE-OFF MASS	*6200 Kg*	*6300 Kg*
THRUST (ISA, SLS)	*9700 lb* (2 x DV-2S) *11300 lb* (growth capability)	*12200 lb* (1 x F-125X)

fig 9

EFFECTIVENESS COMPARISON

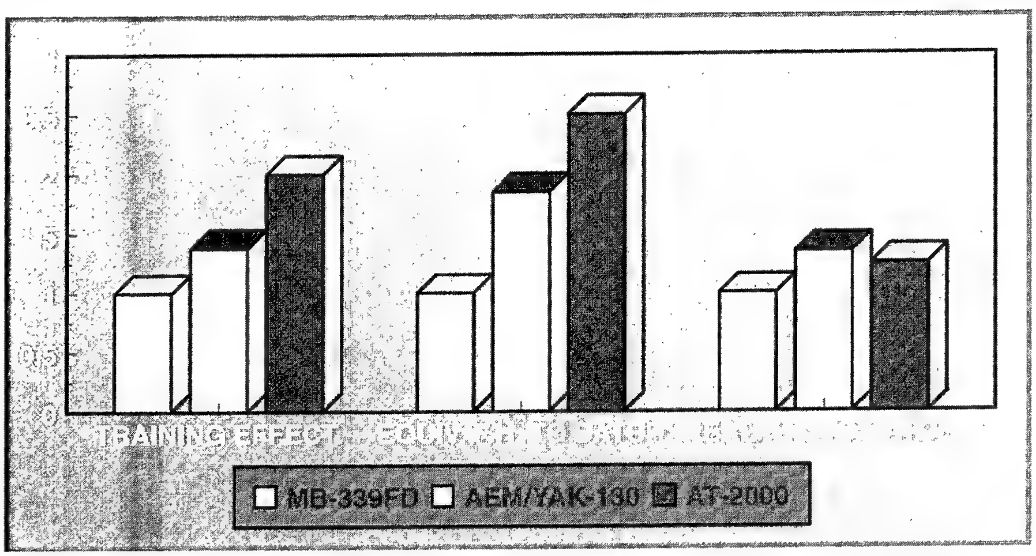

fig 10

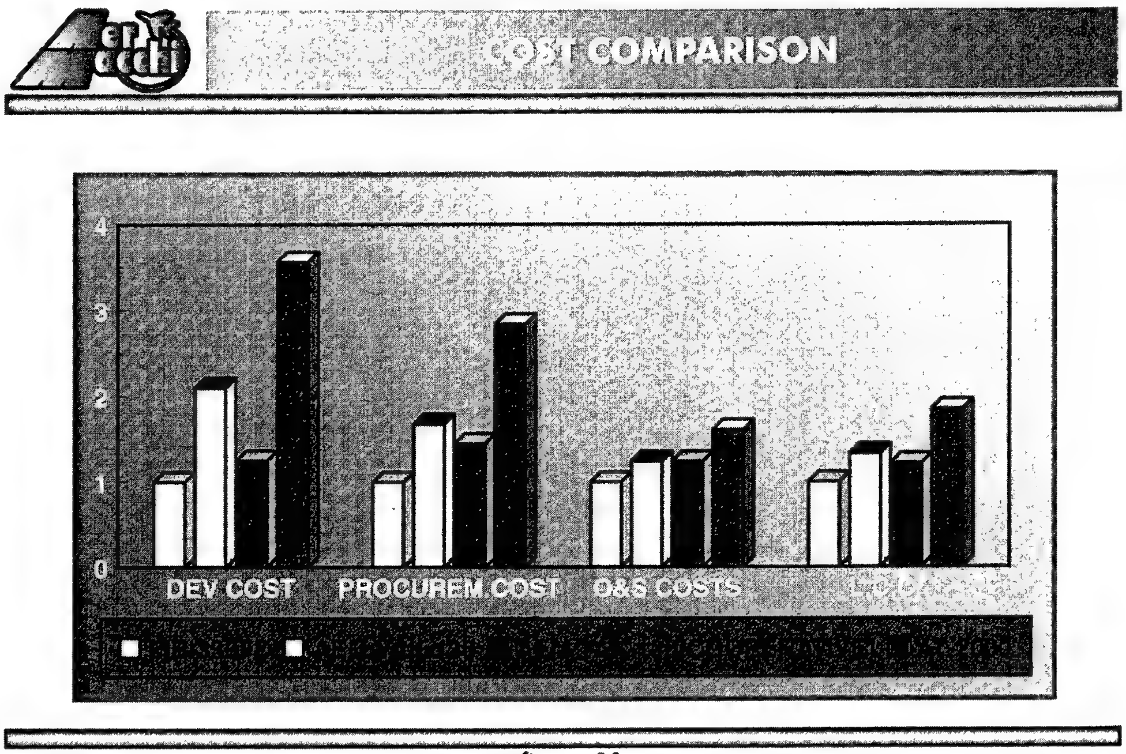
COST COMPARISON
4
3
2
1
0
DEV COST
PROCUREM.COST
O&S COSTS

fig 11

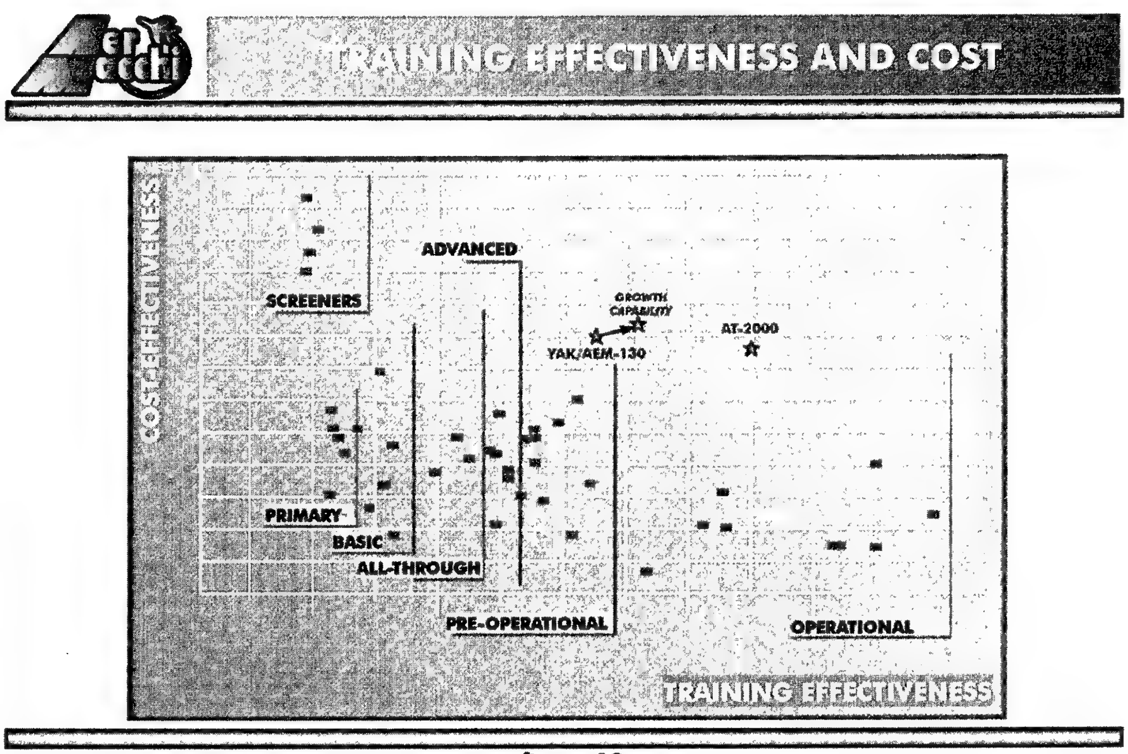
TRAINING EFFECTIVENESS AND COST
COST-EFFECTIVENESS
SCREENERS
ADVANCED
GROWTH CAPABILITY
AT-2000
YAK/AEM-130
PRIMARY
BASIC
ALL-THROUGH
PRE-OPERATIONAL
OPERATIONAL
TRAINING EFFECTIVENESS

fig 12

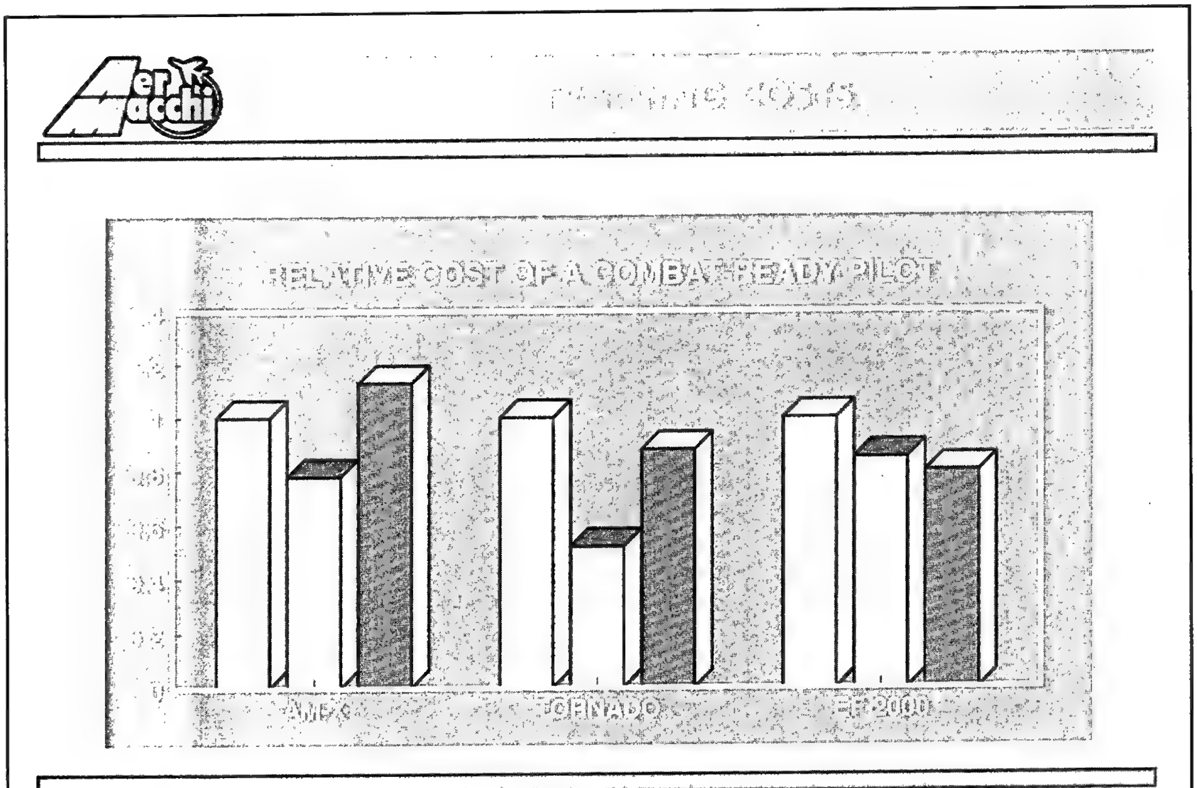
RELATIVE COST OF A COMBAT READY PILOT
AMX
TORNADO
EF 2000

fig 13

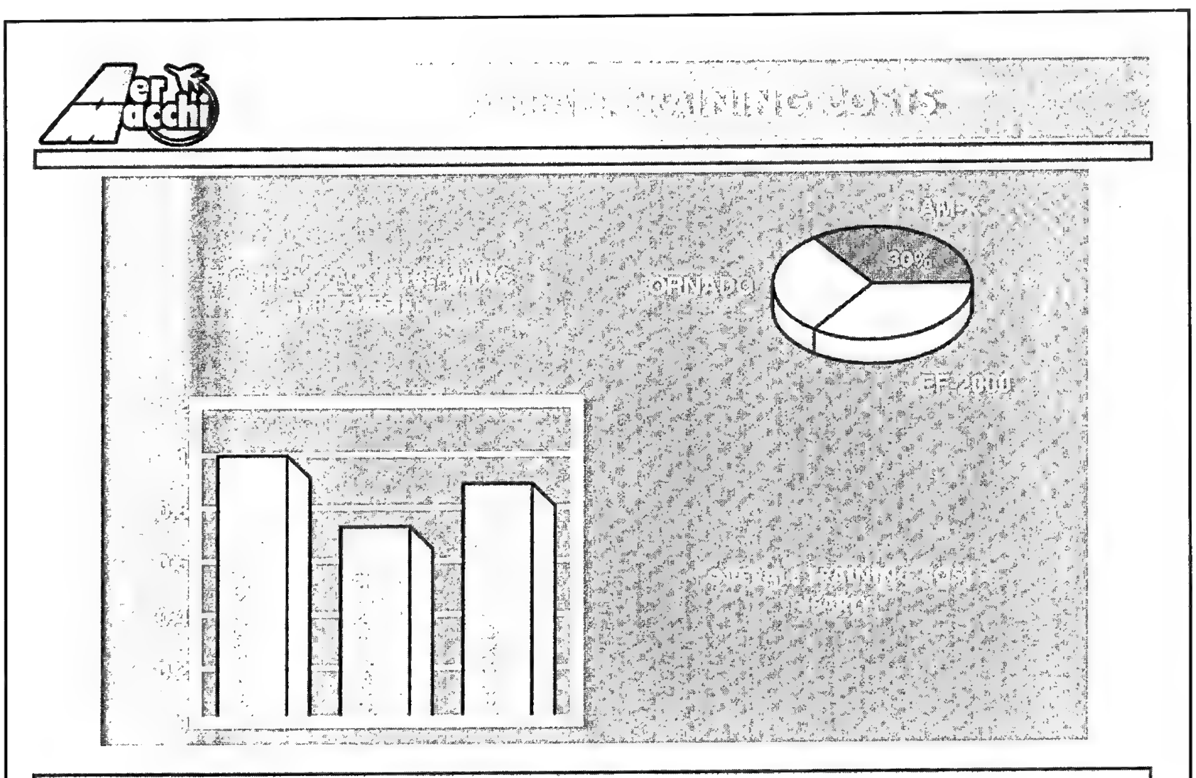
AMX
30%
EF 2000

fig 14

Joint Strike Fighter

Cost Modeling in the JSF

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Summary

This paper is about the Joint Common Cost Model, a cost model developed to meet the unique challenges of estimating the cost of the Joint Strike Fighter Program. The cost model was developed to estimate the cost of a family of aircraft with maximum design and manufacturing commonality which meets the requirements of the United States Navy, Air Force, Marine Corps as well as the United Kingdom's Royal Navy. The JCCM incorporates the effect of commonality among different Service variants, the cost of advanced material composition, the cost of low observability, the costs of a robust avionics suite, the costs of a propulsion system capable of conventional flight and short take off and landing, and the cost effects of affordability initiatives in the area of Producibilty and Manufacturing. To our knowledge a model that meets these difficult requirements had not previously been developed.

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

1.0 Introduction to JSF Program

The Joint Strike Fighter (JSF) Program is an aircraft development effort to design and produce the next generation of affordable strike fighter aircraft for the U.S. Air Force, Marine Corps, Navy, and UK Royal Navy. Each Service variant will be a member of a highly common family of aircraft. Figure 1 illustrates the high degree of commonality that will allow the development and production of Service variants more inexpensively than separate programs. The U.S. Air Force variant will be a conventional take off and landing aircraft, the Navy variant will be suitable for catapult-assisted takeoffs and arrested landings aboard aircraft carriers, and the Marine Corps and Royal Navy variants will be capable of short take off and vertical landing. All variants will feature a high amount of composite material usage in the airframe, a robust integrated avionics suite, and a main engine derived from the F-22 program.

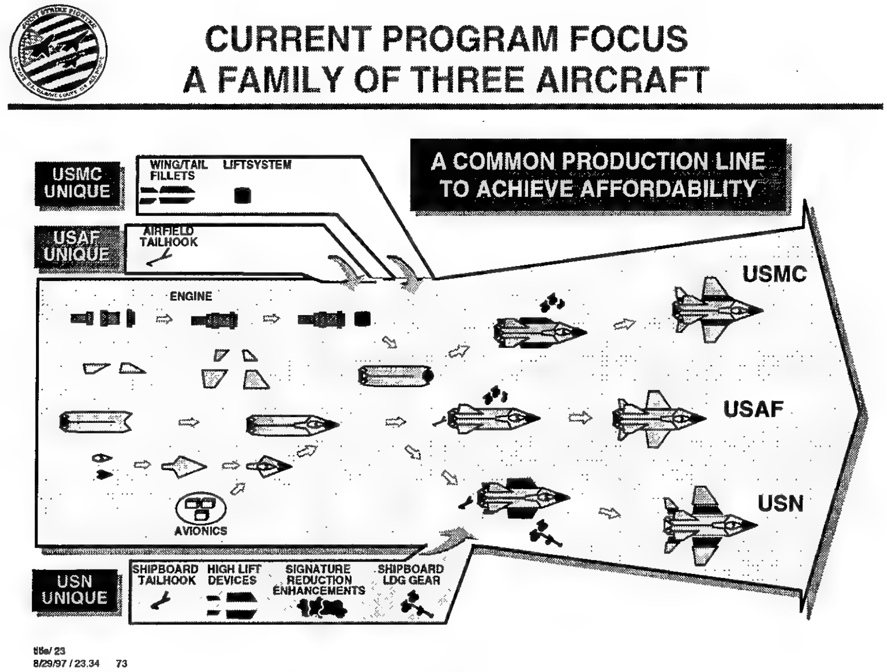


Figure 1

The program emphasizes affordability in all phases—development, production, and operating and support. The program and its contractors are implementing new business practices and the program is funding technology maturation efforts during the current concept development phase. These technology maturation efforts will reduce the risk of transition into the Engineering and Manufacturing Development (EMD) phase as well as reduce development costs. These also help the program meet the cost goals it has established for the unit recurring flyaway cost of each variant in production and reduce the operating and support cost of the aircraft.

2.0 Introduction to JCCM

The Joint Common Cost Model, or JCCM, was developed by the JSF Program Office and the Service cost estimating communities. Figure 2 illustrates the architecture of the JCCM. The JCCM is a parametric cost model which estimates the Engineering and Manufacturing Development (EMD) and Production phases of the JSF program. This model uses Cost Estimating Relationships (CER) statistically driven from U.S. Navy, Air Force, and Marine Corps Fighter/Tactical aircraft cost database. The JCCM was developed and is being improved periodically to estimate the unique aspects of the JSF program. The JCCM incorporates the cost effects of commonality among Service variants, estimates separately the cost of each Service variant, is sensitive to the material composition of the airframe, incorporates the cost savings due to affordability initiatives, and is sensitive to the design and rate and overhead differences between the two competing weapon system contractors. The inputs of the model is based on Weapon System Contractor's (WSC) Preferred Weapon System Concepts (PWSC).

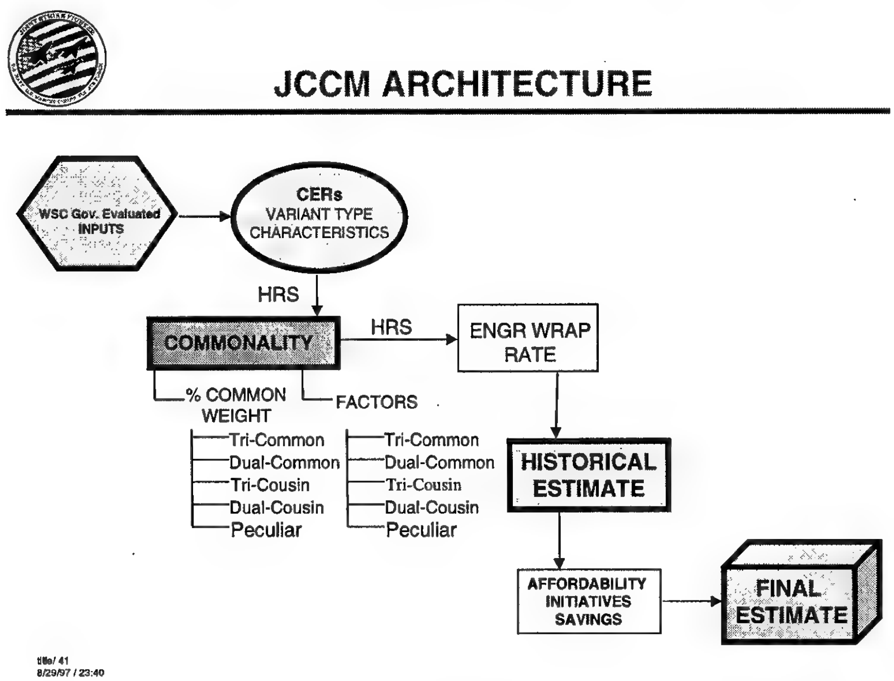


Figure 2

2.1 EMD

The JCCM estimates all EMD costs. Major Work Breakdown Structure (WBS) elements include the Air Vehicle, including Airframe, Propulsion, Avionics, and Armament; System Test and Evaluation; Systems Engineering and Program Management; Data;

Training; Peculiar Support Equipment; Government In-House; and Engineering Change Orders.

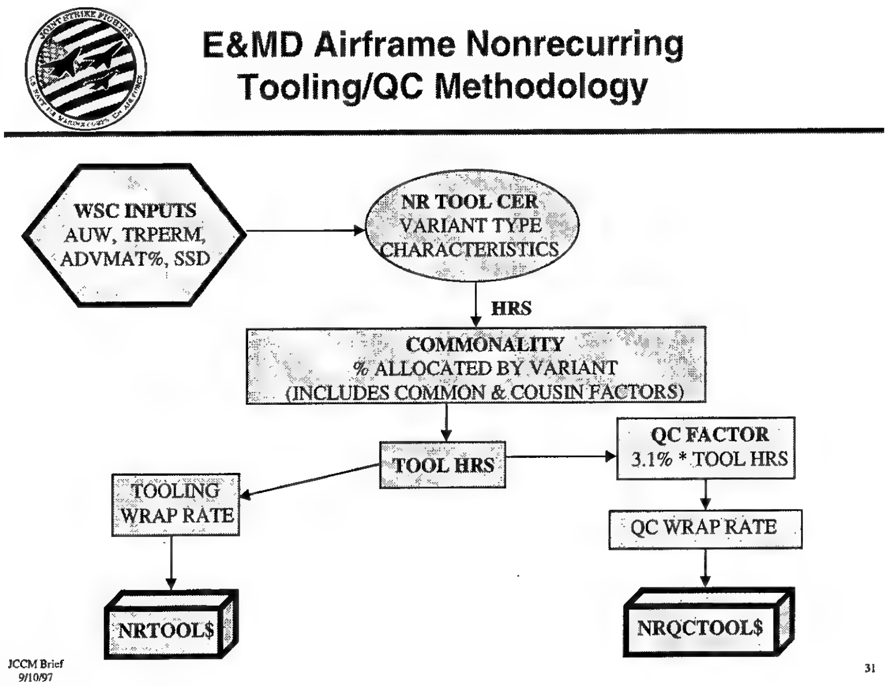


Figure 3

2.1.1 EMD Air Vehicle

The methodology for Airframe EMD labor costs uses parametric cost estimating relationships based on historical military aircraft development programs. The Airframe labor costs are estimated using the traditional functional areas of recurring and non-recurring engineering, tooling, quality assurance, and manufacturing. The costs of labor in these functional areas are aggregated to total airframe costs. For example, the largest labor area in the EMD phase of the program is airframe non-recurring engineering. The non-recurring engineering CER has independent variables for weight empty, first flight date, carrier suitability, supersonic capability, stealth, and material composition. The weight empty is the most significant variable. The carrier suitability, supersonic capability, and stealth are dummy variables. The CER estimates engineering labor hours which are converted to dollars by using each contractor's labor and overhead rates.

Airframe raw material, purchased parts, and purchased equipment costs are estimated using CERs from recent military aircraft programs. The methodologies are sensitive to the material mix and equipment of each variant.

The Propulsion EMD estimate is done at the engine component level such as combustor, fan, turbine, etc. The methodology for the main engine is an analogy to the F-119 engine used on the F-22. The baseline F-119 analogy is adjusted for technical complexity in the areas of performance, technical risk, and manufacturing by engineers familiar with the program to derive JSF engine component development costs.

The methodology for Avionics is an analogy to the F-22 avionics suite. The avionics estimate is built up from avionics elements such as control, navigation, and instrumentation; radar; sensors; controls and displays; core processor; electronic warfare; vehicle management system; etc. Again, the baseline analogy is adjusted for performance, design, and other differences by engineers and analysts familiar with both programs.

2.1.2 Other EMD Elements

System Test and Evaluation is estimated by its separate WBS elements of Contractor Flight Test, Ground Test, Avionics Test and Evaluation, Subsystem Test and Evaluation, and Other Test and Evaluation.

The methodology for Contractor Flight Test is based primarily on a labor hours per flight analogy to a recent fighter aircraft contractor flight test program.

The methodologies for the remaining System Test and Evaluation elements of Ground Test, Avionics Test and Evaluation, Subsystem Test and Evaluation, and Other Test and Evaluation are based on average hours per pound from two historical fighter development programs.

System Engineering and Program Management and Data costs are estimated as part of the same CER as is used to estimate the Airframe non-test non-recurring engineering hours. Twenty two percent of those hours are allocated to Systems Engineering and Program Management, two percent to Data, and the remaining 76% are allocated to airframe non-recurring engineering.

Training and Peculiar Support Equipment are estimated as factors of Air Vehicle plus non-ILS Systems Engineering and Program Management less Engine costs.

Government In-House costs are composed of Ground Test Facilities, Flight Test Facilities, Program Office, and Small Business Innovative Research. Government Ground Test Facility wind tunnel costs are estimated as a rate from the facility per occupancy hour. Sled test costs are estimated by cost per test.

Government Flight Test Facilities are estimated as a rate per hour from the flight test location.

Program Office costs are estimated as rate per person using current program office staffing levels.

Small Business Innovative Research is a factor of the previously estimated program development cost.

2.1.3 Commonality

The JCCM explicitly estimates the effects of commonality for Air Vehicle costs. The treatment of commonality is a rigorous process which begins with a government team that assesses commonality by individual part. The team looks at the size, shape, material composition, and function of each part. The degree of commonality of each part is assessed at a basic level as common, cousin, or unique. Common parts are defined as physically identical. Cousin parts are defined as having the same material, function, and interfaces, and similar internal geometry. For example, cousin bulkheads are made of the same material, serve the same function, and have the same external dimensions, but have similar web thicknesses and number of penetrations. Cousin parts share common fabrication or assembly tooling. Unique parts are defined as having application to a single variant.

Within these three basic definitions of commonality there are additional levels of commonality according to the number of variants that have that level of commonality. For example, common parts can be tri-common among all variants, dual-common between the Air Force and Marine Corps variants, dual-common between the Air Force and Navy variants, or dual-common between the Marine Corps and Navy variants. There are the same additional levels for cousin parts.

Every part in the airframe is assessed for commonality. The weights of the parts are summed for each level of commonality. The commonality levels for an airframe can then be expressed as a percentage of total airframe weight. For example, 50% tri-common means that half the weight of the airframe consists of parts that are common among all three variants.

The next step in determining the cost effects of commonality is determining the amount of non-recurring and recurring effort saved for each level of commonality. For the non-recurring costs of design, tooling, and quality control, a government and industry team studied each functional process to determine how much effort would be saved for each level of commonality relative to performing the effort separately for each variant.
The non-recurring cost effect of commonality is expressed as a factor relative to the cost of performing the effort separately for each variant, or uniquely. Unique effort has a commonality factor of one, meaning that no effort is saved. Effort assessed as common

or cousin has a factor of less than one. The factor is multiplied times the effort estimated for a unique aircraft.

Consider the example of the design process for unique versus common parts. No design effort is saved for unique parts because each unique part must be designed separately for each variant. So the commonality factor is 1 for the Air Force variant plus 1 for the Marine Corps variant plus 1 for the Navy variant, or 3, divided by the number of variants, which is 3. So the commonality factor for design of a unique part is 1, and the non-recurring design cost of unique weight in each variant gets multiplied by 1.

At the other extreme of commonality is tri-common parts, those that can be used for all variants. The part must be designed initially for the first variant. Then additional trade studies in stiffness, loads, stress, etc., as well as finite element modeling must be done to ensure the part's use in each of the other two variants. The government and industry commonality team determined that this additional effort is a factor of .2 (two tenths) of the cost of designing a unique part. So the non-recurring design cost of a tri-common part is 1 for the Air Force variant plus .2 for the Marine Corps variant plus .2 for the Navy variant, divided by the number of variants, which is 3. This fraction gives a commonality factor for design of tri-common parts of .47, and the non-recurring design cost of tri-common weight in each variant gets multiplied by .47.

The commonality methodology for recurring costs is similar to the methodology for non-recurring costs. The same commonality weights and percentages are used as in the non-recurring methodology. The cost effects of commonality are estimated using learning curves. Tri-common parts are run down a learning curve for the total quantity of aircraft produced. Unique parts are run down separate learning curves for the quantity of each variant. The weights of cousin parts are split into either the common or unique category using factors determined by the commonality team and then run down the appropriate learning curve. For example, parts that are dual cousin between the Air Force and Navy variants have 84 percent of their effort run down a common Air Force and Navy learning curve and 16 percent of their effort run down unique Air Force and Navy curves.

To summarize the treatment of commonality, commonality is part of the estimate for all the functional labor areas of the airframe as well as for the raw material and purchased equipment. Commonality is also applied to avionics and propulsion.

2.1.4 Stealth

The JCCM estimates the cost of stealth by using CERs and factors. The Program Office is conducting cost research to quantify the costs of specific stealth measures in an effort to estimate those items discretely.

2.1.5 Affordability Initiatives

The JCCM estimates the savings from affordability initiatives separately to maintain visibility and because of the difficulty in estimating these initiatives. The initiatives are identified and the cost savings are quantified in a separate database. The Program Office is conducting cost research to assess the cost and technical feasibility of the initiatives and will continue to update its estimates of them.

2.1.6 EMD Summary

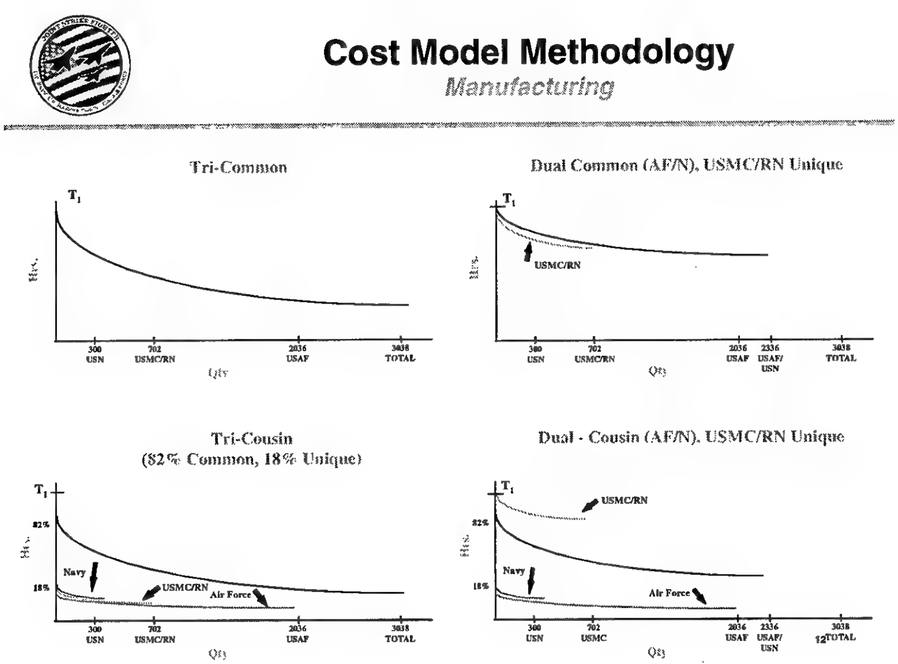
The EMD phase is scheduled to begin in FY2001. The total EMD estimate is in the range of $15 to $17 billion in FY 95 dollars. *(Steidle in Johns Hopkins APL Digest)*. This is roughly half of what it would cost to develop each variant as an individual program.

2.2 Production

The Production phase is estimated using the same CERs as are used to estimate the EMD phase. A step function adjusts from EMD Manufacturing to Production Manufacturing, but the learning curve and commonality methodologies are the same. The JSF program has a notional production profile which is used to estimate production costs. The quantities for planning purposes are 2036 Air Force units, 642 Marine Corps units, 300 Navy units, and 60 Royal Navy units. The commonality effects of the production profiles are illustrated in Figure 4.

The production estimate includes costs for Engineering Change Orders. Change Orders are estimated as a declining percentage of Airframe costs over the production run. The percentage is an analogy to a similar fighter aircraft program.

Figure 4



3.0 Summary

The JCCM was developed specifically to estimate the EMD and Production phases of the Joint Strike Fighter Program. The model provides visibility into the Program's areas of special interest such as commonality, material composition, and affordability initiatives. The model supports cost and operational performance trades and thus supports the Program's vision of developing and producing an affordable strike fighter. The model produces estimates in support of budget and planning exercises.

Reference

Steidle, C. E., The Joint Strike Fighter Program, TECHNICAL DIGEST, Johns Hopkins APL, Jan – Mar 1997, Vol 18, No. 1

List of Acronyms

JSF	Joint Strike Fighter
JCCM	Joint Common Cost Model
USN	United States Navy
USMC	United States Marine Corps
USAF	United States Air Force
EMD	Engineering & Manufacturing Development
CER	Cost Estimating Relationships
WSC	Weapon System Contractor
NR	Non-recurring
QC	Quality Control
AUW	Airframe Unit Weight
TRPERM	Total Rate per Month
WBS	Work Breakdown Structure

SIMEN An In-house Simulation Tool, Reducing Risk and Cost for the NSM Development Program

by

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SUMMARY

This paper describes the simulation tool (SIMEN) developed to support a cost-effective and low-risk development of the new anti-ship missile (NSM) for the Royal Norwegian Navy (RNoN).

Missile test firings are very expensive, difficult to plan and predict, and they seldom cover all test scenarios. Therefore, computer simulations in our missile programs have become more and more important as powerful computers and SW tools are getting more cost-effective. Powerful visualisations of simulations make SIMEN a useful tool for everybody working with NSM.

One of the main goals with the use of SIMEN is to help the project detect errors in the missile system as early as possible to minimise the costs and technical risks.

1. INTRODUCTION

KONGSBERG GRUPPEN ASA is facing several major tasks in connection with the development of an advanced, new anti-ship missile system (NSM) for the RNoN. In order to reach our ambitious goals, we decided that a complete simulation system was needed to support the project. The system, SIMEN (SIMulation ENvironment), will be our most important tool in the design, test, evaluation, manufacturing and maintenance phases of the product.

NSM will have multi-platform capabilities, and is planned to be integrated on new fast patrol boats, new frigates, mobile coastal artillery units and helicopters. The missile will be autonomous, highly manoeuvrable and will have low signature and weight. The development period is relatively short and the economical budgets are tight in achieving the wanted missile performance. We will use new technologies regarding propulsion, image processing, processor systems and programming language. This has forced us to look at development methods which can reduce the technical and economical risks of this project.

An overview of the NSM missile system architecture with external interfaces is shown in Figure 1.1. NSM deliverables are Missile System Administrator (MSA) and Launcher with missile.

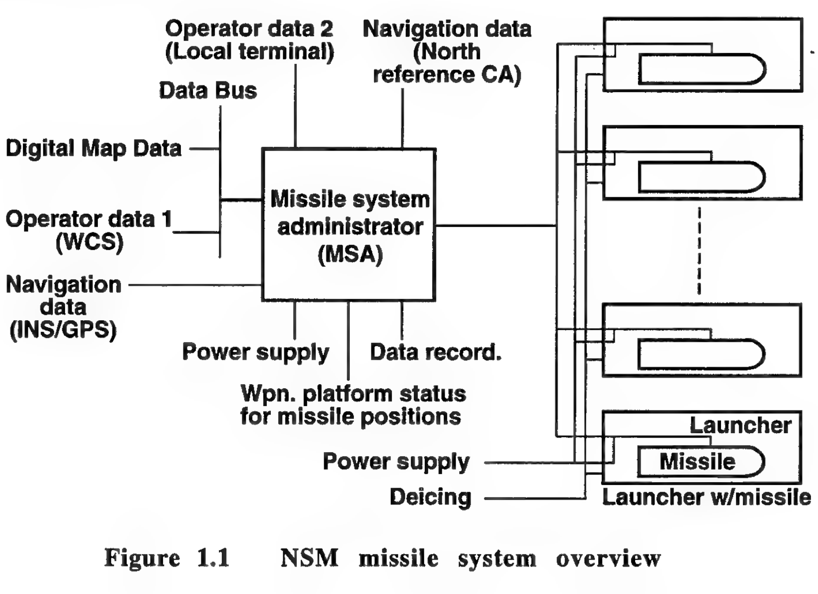

Figure 1.1 NSM missile system overview

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

2. WHY SIMULATE?

Simulations have always been used as a test tool in our other anti-ship missile programs (Penguin). There exist both numerical simulators (implemented in FORTRAN) and several special hardware (HW) simulators. These simulators have been used mainly as a supplement for different tests (e.g., test firings) and not for verifications.

In the NSM project, very few test firings are planned, and all are expected to be hits. Therefore the project management has decided to put a lot of effort and money into a total and integrated simulation system. In the long run, the SIMEN investment cost will be paid back several times by the system's early detection of many of the expensive errors that can occur at the end of the project.

By making a common simulation and verification system for the engineers in the project, we expect to:

- dramatically reduce the need for expensive test firings of missiles. Thousands of simulations can be done for the cost of one test firing.
- test both possible and "impossible" scenarios in-house, because we can model whatever we want.
- reduce the development and test period by working more cross functional.
- increase the amount of software (SW) and HW reuse, because test equipment is made only once.
- find errors early in the development phase, because a lot of people will be testing other peoples SW and HW every day.
- have a helpful configuration tool for the Concurrent Engineering process NSM will use.

There will be needs for different types of simulations in different phases of the project. In the conceptual system design phase, for example, there is a need for a quick tool to give a rough overview of the system. Detailed models are needed for the detailed algorithm design, and detailed interfaces and time delays are needed for real-time design and testing. The tool has to be flexible enough to handle all these needs without becoming too slow and complicated to use. The project engineer will be able to pick the needed test-ingredients (HW or SW) "off the shelf", and create the wanted test configuration. The major challenge for SIMEN is to fulfil the projects needs into a flexible concept and at the same time be a step ahead of the rest of the project in the development phase.

SIMEN will not be a single simulation program, but rather a set of different available tools for the project. The different tools will be used for different or complementary tests. SW and HW reuse between these simulators are highly stressed. That will help us make user-friendly tools which are tightly inter coupled.

3. NUMERICAL SIMULATION

Mathematical models of the entire missile system (MSA and several Launchers with missiles) and its relevant environment are developed through object-oriented methods and implemented in C++. SIMEN-models will be executed on distributed work stations or on a powerful multi-processor machine.

Among other things there will be mathematical models of:

- missile system sensors (inertial measurement unit, altimeter, gps, seeker)
- missile system actuators (control surfaces, jet-engine, booster)
- missile dynamics
- missile warhead
- environment scenario covering wind, waves, terrain, targets, Close In Weapons Systems (CIWS), decoys
- launch platform, including the weapon control system and relevant sensors

These models, together with support functions (user interface, equation solver, logger, parser) and the actual missile system SW (algorithms for mission planning, navigation, guidance & control, image processing and telemetry), will form our numerical simulation tool.

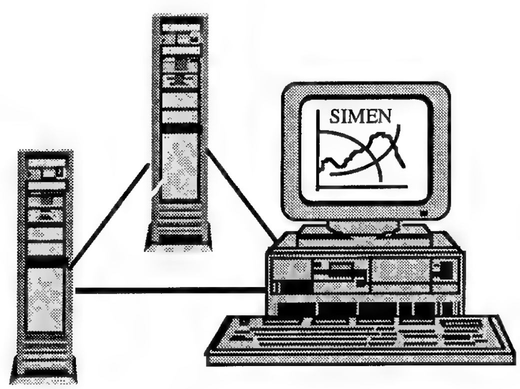

Figure 3.1 Numerical simulation

The numerical simulation tool will be used to:

- prototype and visualise a conceptual design for the customer
- do tactical investigations
- develop the missile system SW algorithms
- examine the stability and robustness of the missile
- test different flight paths

- test the algorithms with expected and non-expected environment conditions
- do tests which are impossible to plan in real environments (e.g., loose wings, engine breakdown)
- do open-loop filter-tests (Monte Carlo simulations)
- test the salvo-function
- test the weaving and terminal phase
- perform pre- and post-simulations in connection with test firings

Our main advantage is that we will use identical missile system SW, both on the target processors and in SIMEN without changes except recompilation. The fact that the missile system SW is developed within the simulation environment reduces the development cost and technical risk of the project. To be able to port the missile system SW from host to target processor, we are developing a special SW infrastructure for each operating system used. The purpose of the infrastructure is to allow changes on the target computer without changing the missile system SW. This is done by encapsulating the implementation of the operating system functionality (e.g., communication method, timers, task distribution) from the missile system SW.

The systems message sequences are fully controlled by the simulator, and therefore all simulations are repeatable when executed with the same models and the same simulation input. Since the sequences are controlled, the simulations can be executed in real time, and slower or faster than real time dependent on the complexities of the models.

There will exist several versions of each mathematical model (ideal, simple and complex) which can be configured to fulfil different simulation needs. The models have to be as real as possible at every step in the development phase. Therefore, the mathematical models will be updated continuously during the project with measured data from, for example, wind tunnel tests, separate sensor/actuator tests, environmental tests and test firings.

4. HARDWARE-IN-THE-LOOP (HWIL) SIMULATION

In HWIL simulation, the hardware replaces mathematical models and allows us to test actual missile subsystems under closed- or open-loop conditions. Hence, on an early basis, we can test the HW interfaces and the real-time capabilities of the system.

In SIMEN there are several HWIL test configurations with different purposes.

4.1 Lab tests

The first step in our HWIL test is to port the missile system SW to the target computers. Some or all of the missile system SW executes on the target computer, while the mathematical models execute on the simulation computer or a VME-based rack (SIMEN rack) to generate the correct stimuli to the target SW.

The second step is to gradually substitute some of the simulation models with actual missile actuators or sensors. These simulations claim real-time execution for the overall simulation system. HW or logical mismatch between missile system components can then be discovered and fixed by incrementally integrating the different HW components. In addition, the real-time capability of the system can be examined and tuned.

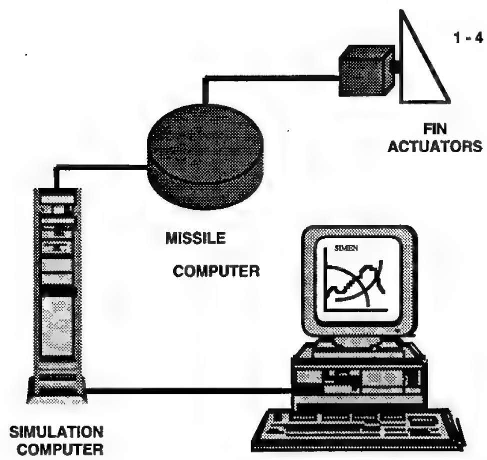

Figure 4.1 HWIL simulations, lab tests

4.2. POD flights

Some of the missile system HW demands high g-movements (e.g., inertial measurement unit (IMU)) or real environment (e.g., IR seeker) to run a proper sensor test. In order to achieve this, we will instrument a fighter aircraft fuel tank/pod with missile system components and SIMEN equipment, and fly appointed manoeuvres while recording the sensor data. These data will then be used "as is" in open-loop lab tests and to calibrate our models for future numerical simulations.

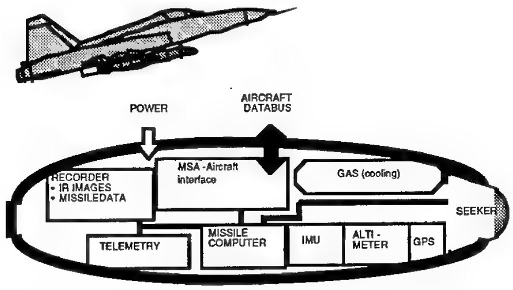

Figure 4.2 POD flights

4.3 Technical evaluation firings

When the whole missile system (launcher with missile and MSA) is ready for technical evaluation firings, some of these tests will be done without an actual weapon platform, but rather from a fixed installation. To perform these evaluation test firings, NSM will get its stimuli from a weapon platform simulator built into SIMEN. In these tests there will be a weapon platform simulator together with an actual launcher with the missile to be fired, an actual missile system administrator and the real test environments.

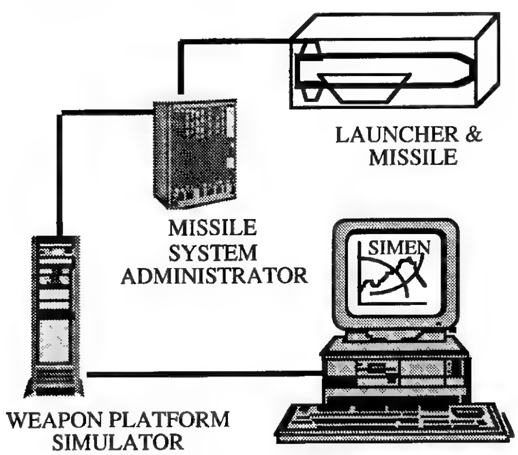

Figure 4.3 Weapon platform simulator

Test firings from a simulator mounted on a dummy weapon platform will serve as part of the final verification of the missile system. But before we reach this point in the program, a huge number of simulations for test and verification of sub-functions of the system will have been done with other parts of SIMEN.

4. DEVELOPMENT METHODS

SIMEN will be the main development and test tool for NSM. This will require development methods which are at least as good as the standards for the missile system components. Integrated teams will help us develop models which coincide with the real behaviour of the system. In addition, the system will be updated with new data from other tools and tests. SIMEN will be put under configuration control so that every version is reproducible.

5. CONCLUSION

Throughout the project, the focus and use of SIMEN will change from purely numerical design simulations to fire-control unit simulations used for verification of the missile system at test firings. SIMEN will also be an important tool in connection with possible mid-life updates of missile system components.

SIMEN will be well modularised, and, with minor changes, it can be used to simulate any other system with similar characteristics (e.g., new missile systems, operator trainer). This will give us a head start for future development programs in KONGSBERG GRUPPEN ASA.
But first SIMEN will be a very important tool to ensure the success for the NSM project!

Parametrics as an Adequate Cost Estimation Tool for Affordable High – Tech Products

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Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

It is my understanding that this panel of AGARD deals with highly sophisticated technical matters, extending the edge of technology into the unknown and satisfying the human mind in so far as it gives a better understanding of physics and nature and hopefully has very practical consequences for applications.
My subject deals with the affordability of such applications. This means an understanding of nature as well but it is the human nature and human behaviour in engineering groups and programme teams consequences that matter if we want to understand the ultimate cost drivers that are the key elements of cost origination.
Our highly organised societies in their education, trading, administration, energy, transport and defense sectors for their mere functioning depend in an indispensable way on technical systems reflecting the complexity of the demands. We do not have the choice to turn back the clock for the sake of simplicity. Our concern, therefore, must be to keep those systems affordable, as we cannot do without them.
It remains a chicken-and-egg problem whether education produces a certain mental condition or the other way round. But the abilities to cope with the problems of fast developing high-tech societies will most certainly not come from the "book and stock keeping" education combined with that typical mentality nowadays dominating leadership in industry and administration. As far as we can see cost and money crises are just indicators for the incompetence of the present setups in industry, bureaucracy, governments and society to deal with the problems.
The writing is on the wall.
Aren't there then all those buzz words and "Rainmaking Ceremonies" like Total Quality Management, Lean Management, Business Reengineering etc. that eternal promise of everything for anything? Some of them are quite pathetic and they very often do not apply to an industrial society built on different educational goals and cultural achievements with an almost unique "pyramid of competence". This setup with universities at the top, well organised engineering communities in small and big industries, those almost perfect just-in-time factories as well as the very widespread highly educated and well trained mechanical craftsman at the bottom layer of the industrial pyramid which has produced and maintained "High Tech" in one way or the other for the last 200 years. Everything looked so perfect.

- But the end of the cold war and the resulting fall down of a challenging world power has shaken up all previous arrangements and provides now for very different challenges and a dramatic change in scenarios for the NATO world and their global neighbourhood.

- We, therefore, have to rethink, redesign, reengineer, remanufacture most of the processes and procedures in view of the de facto globalisation; consequently there is a need for new tools and methods.

Do we at all have those tools and methods for dealing with those problems in an adequate manner?

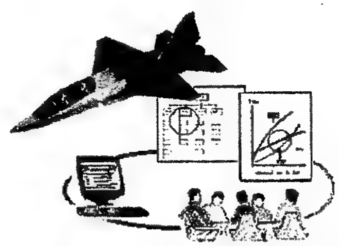
Oh yes, we have!

Parametrics is indeed one of these tools developed in America that can really assist in certain specified areas. Producing reliable cost estimates has always been a problem directly interlinked with the complexity of any projects.
How can Parametrics as an engineering estimating method help to produce affordable high-tech products? What is Parametrics really?
With a few slides I would like to give you an idea what can be done and how it is done and how it is applied.

PARAMETRIC

Dasa

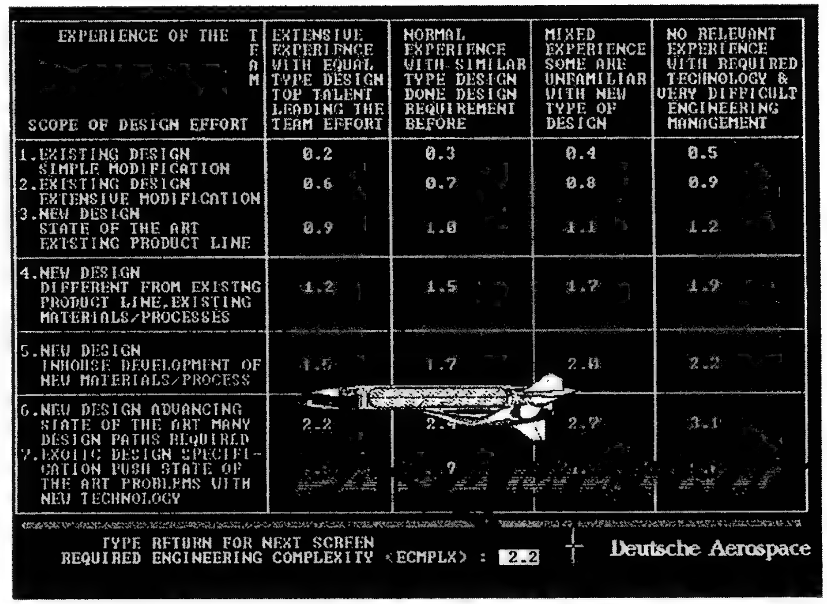
- is an Engineering method of Cost Estimating
- is a tool that by now has 20 years of maturity
- is a combination of many CER's into one model
- is based upon sound Engineering principles
- is using Engineering tools for Engineering problems



Statistics, regression analysis, curve fitting and Cost Estimating Relationships (CER) are the basic ingredients to Parametrics Cost Estimating. Putting equations for CERs together into a mathematical model is the beginning of all Parametrics. CERs are defined by very basic empirically determined mathematical equations:

- how many quartersize/DIN A2 drawings are required to manufacture how many kilograms/pounds of material
- how much effort is related to the grinding, milling, NC-machining or form laying and baking depending on material properties
- how much tooling is required to do this job
- how much integration effort is required to preplan,engineer, design, coordinate, manage and machine the subject item
- how much time is necessary for the individual tasks, how much for the total interactive integrating process.

All of the above is then factored by Technology Maturity, Engineering Complexity, Manufacturing Complexity and the appropriate tooling factors.

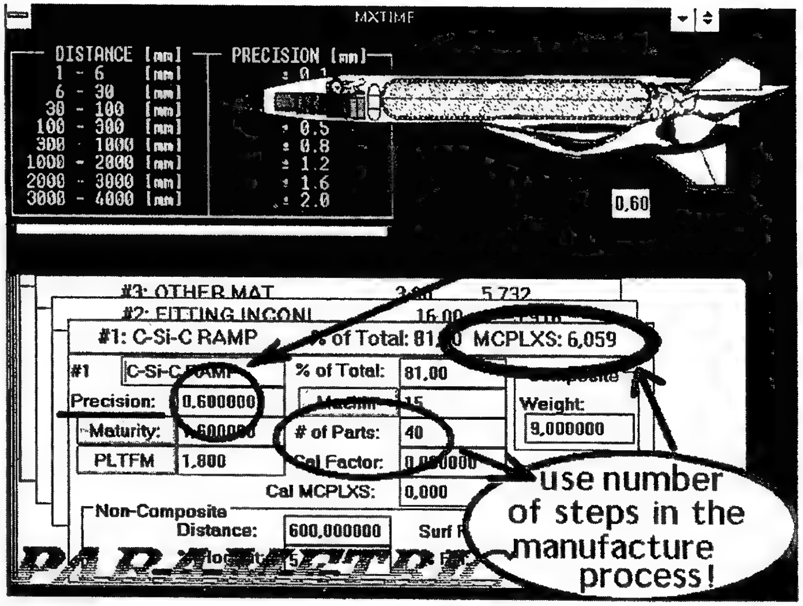


SCOPE OF DESIGN EFFORT / EXPERIENCE OF THE TEAM	EXTENSIVE EXPERIENCE WITH EQUAL TYPE DESIGN TOP TALENT LEADING THE TEAM EFFORT	NORMAL EXPERIENCE WITH SIMILAR TYPE DESIGN DONE DESIGN REQUIREMENT BEFORE	MIXED EXPERIENCE SOME ARE UNFAMILIAR WITH NEW TYPE OF DESIGN	NO RELEVANT EXPERIENCE WITH REQUIRED TECHNOLOGY & VERY DIFFICULT ENGINEERING MANAGEMENT
1. EXISTING DESIGN SIMPLE MODIFICATION	0.2	0.3	0.4	0.5
2. EXISTING DESIGN EXTENSIVE MODIFICATION	0.6	0.7	0.8	0.9
3. NEW DESIGN STATE OF THE ART EXISTING PRODUCT LINE	0.9	1.0	1.1	1.2
4. NEW DESIGN DIFFERENT FROM EXISTNG PRODUCT LINE, EXISTING MATERIALS/PROCESSES	1.2	1.5	1.7	1.9
5. NEW DESIGN INHOUSE DEVELOPMENT OF NEW MATERIALS/PROCESS	1.5	1.7	2.0	2.2
6. NEW DESIGN ADVANCING STATE OF THE ART MANY DESIGN PATHS REQUIRED	2.2	2.4	2.7	3.1
7. EXOTIC DESIGN SPECIFICATION PUSH STATE OF THE ART PROBLEMS WITH NEW TECHNOLOGY	[illegible]	[illegible]	[illegible]	[illegible]

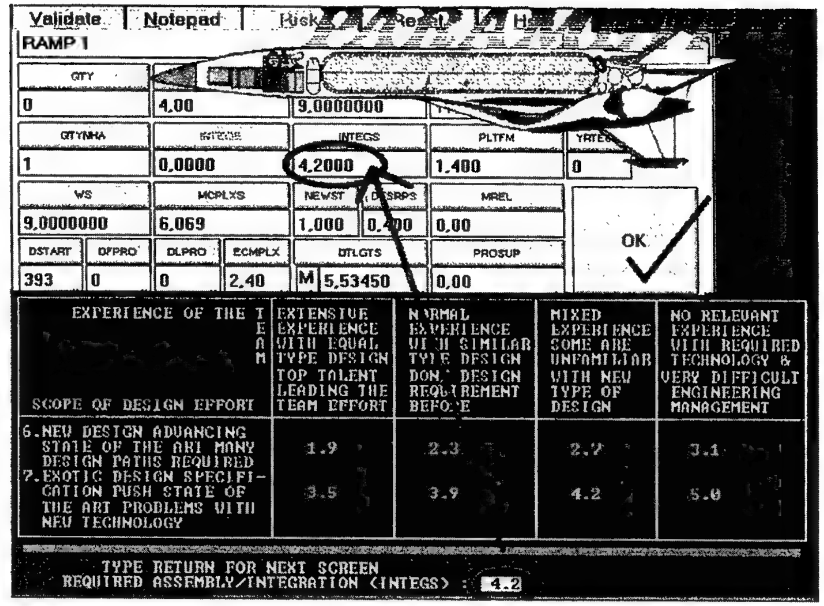
TYPE RETURN FOR NEXT SCREEN
REQUIRED ENGINEERING COMPLEXITY <ECMPLX> : 2.2

Deutsche Aerospace

This and the following tables illustrate – for the purpose of Parametric models – the non-linear relations between the difficulties in a new project and the capabilities of a project team to deal with them. They are defined as Engineering Complexity,Manufacturing Complexity and Integration Difficulty.In other words: we are translating human factors into numbers along established cost estimating relationships.

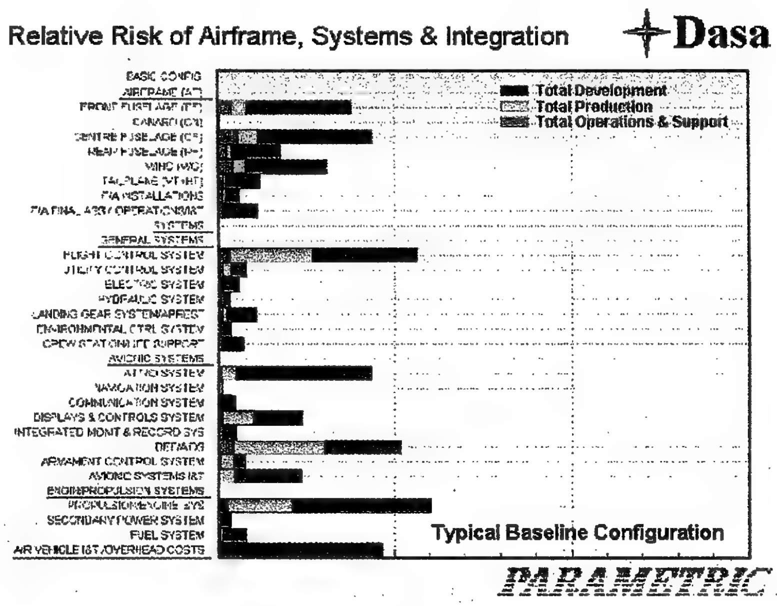


The complexity of manufacturing is being defined by the precision governing the quality of the work piece, the maturity of the production process, the machinability index of the materials used, their weight after hogout and by the number of parts and steps in this process.



The complexity of integration of various kinds of engineering in design, tooling, manufacture and testing is determined likewise by the interrelation of the design effort with the experience of the performing team.

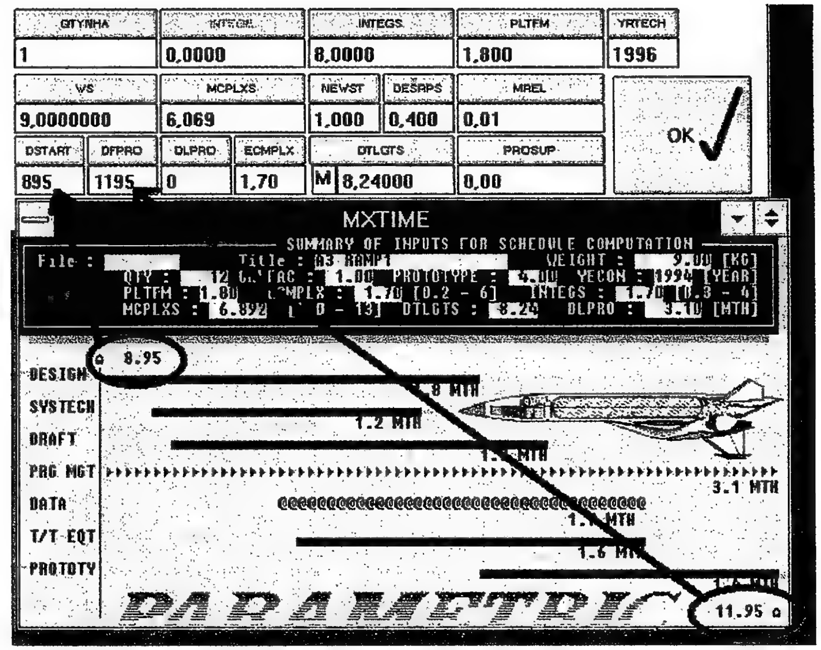
These factors are key cost drivers and describe for the purpose of Parametrics in mathematical models the difficulties which are to be mastered by the design and engineering teams and are as such commensurate with the technical and managerial processes of product development.



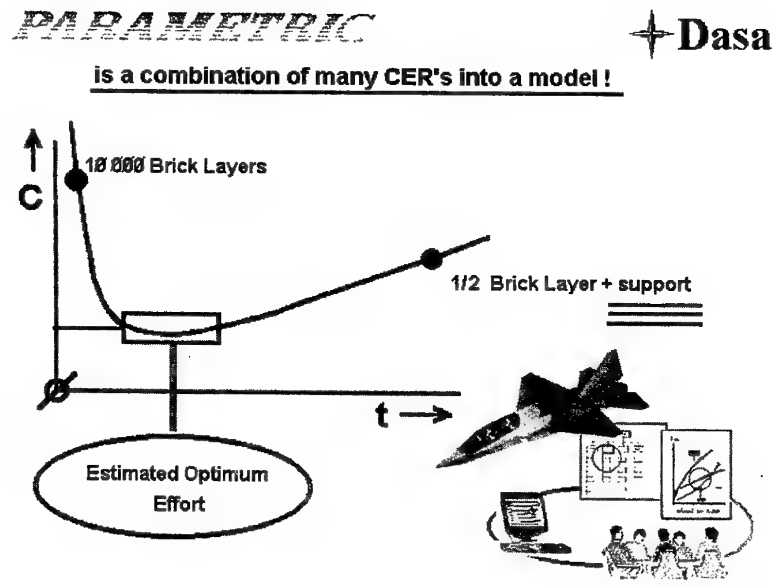
By defining the cost drivers in a scaleable manner for the subprocesses of design, manufacture, integration and testing, Parametrics can isolate the potentially risky areas of a project down to individual subsystems and their constituting equipments and software

This enables:

- careful cost estimates
- profound risk assessment
- consequential Design-to-Cost management



A special remark on schedule and time:
time is this totally unreplacable, not rewinnable resource running along a time line aiming irreversibly at a diffuse future target. We can slow down or stop processes though none is ever totally reversible. Time as a resource is irrecoverable. Not by any money. That implies that particular care must be taken with this unique resource as a topmost cost driver. Any outstanding work which needs to be done but is not performed adequately by adequate people will subsequently be done inadequately, in an inadequate manner by inadequate people. Practically all time relevant processes have their optima. Departing far from such optima is likely to cost a lot of effort and money.

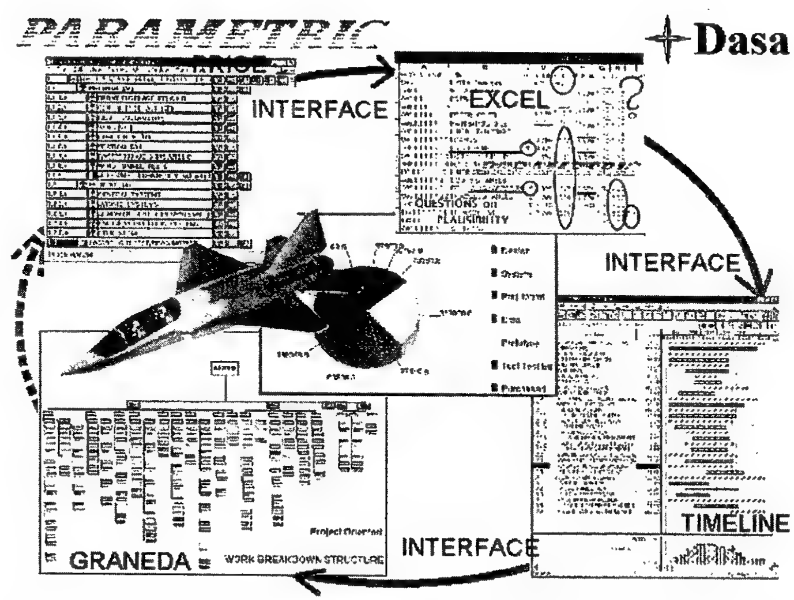


Quite obvious there are those optimisations:

– 10000 bricklayers can not build a house in 2 hours
– one half of a bricklayer with multiple talents may finish it at this short end of infinity just somehow!

The algorithms on time available for a job all inherit the Wilhelm Busch (famous German poet – Tücke des Objekts) or Murphy experience that any given time frame available will be filled somehow; with work or nice excuses for it.

Many projects were ill-fated because, aside of considerable technical difficulties which were often being mastered in the end, there were inadequate cost and schedule estimates at the beginning and a serious lack of understanding in the handling and control of cost drivers throughout the ongoing development programme that pushed the project out of all proportions.

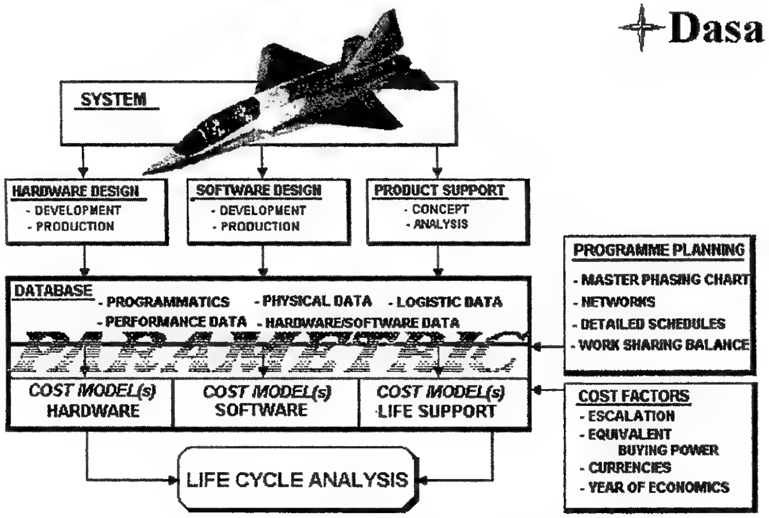


Well optimised Parametric models contain many Cost Estimating Relationships (CER's).

Just a decade ago the victory march of the PCs has stipulated and produced a whole new world of possibilities. Computations which used to take a dedicated Small Frame (such as a PR1ME number cruncher) more than 3 quarters of an hour are now being done in split seconds on PCs even though hundreds of mathematical equations derived by regression analysis are being run through for the final result.

The power of interaction of computational, graphical display, and analysis possibilities on a modern PC workstation are allowing a previously unpredictable combination and interaction of tools and means for the purpose of Parametrics.

Dasa



INTEGRATION IN THE PROJECT WORK FLOW

Parametrics as a methodology, supported by readily available commercial models, therefore, has become a fully accepted partner like any other design discipline within the integrated project design process and work flow, providing for fast estimating capabilities in the hardware, software and life support areas and, therefore, entailing the complete loop of life cycle cost estimating and analysis.

PARAMETRIC

Dasa

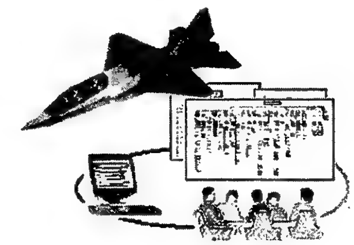
is a source for an independent and reliable estimate

is a project assessment from a different point of view

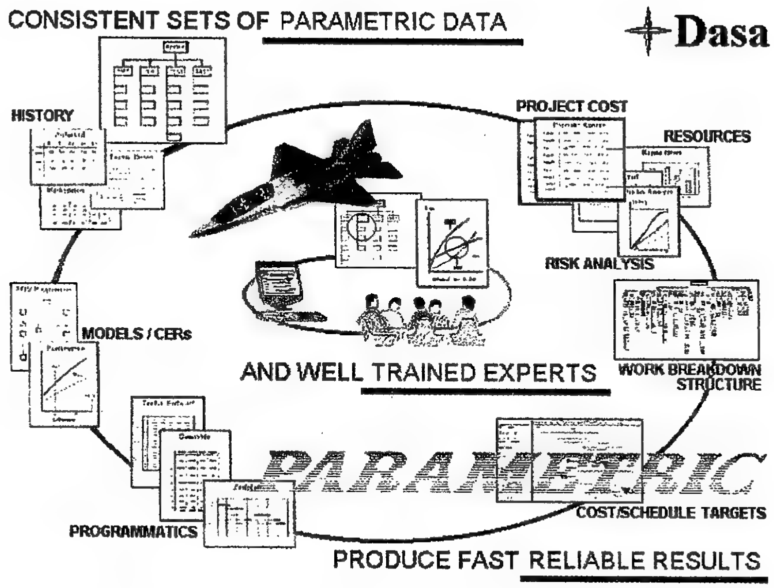
is the systematic and documented use of expert experience

is making use of data readily available in the project

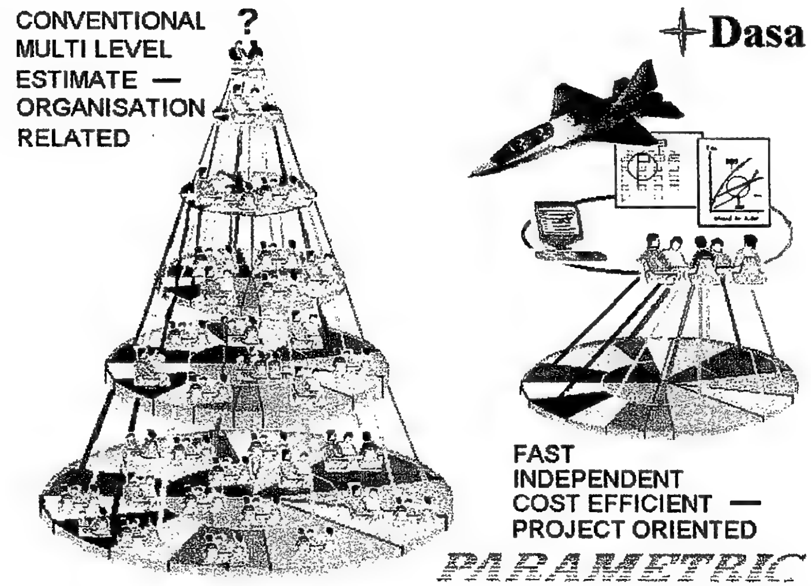
is working early in the project with limited information



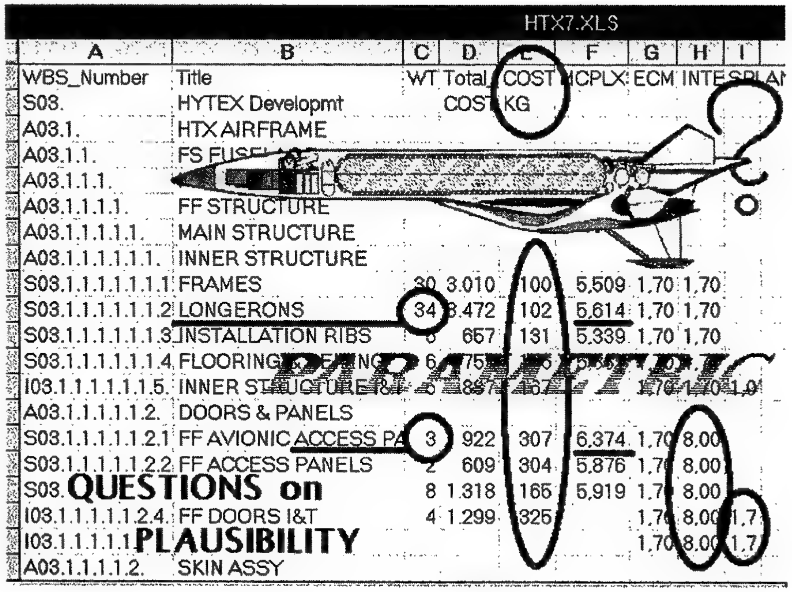
In many aerospace companies both here in Europe, the United States and the Pacific rim Parametrics with well tuned and readily available commercial models such as the PRICE family of models has become the tool of choice for reliable analysis and estimating. Using in a documented and systematic form the expert experience in the projects, based on data inputs which are available anyhow. Parametrics has built a reputation for being capable of estimating even in early project phases with the limited information being accessible at that time.



Engineering, planning and concept imagination can be transformed by Parametric experts into firm, adjustable parameters on a detail-by-detail basis .This will be combined with and embedded in a real hardware and software oriented project work breakdown structure that allows the repeatable process of documentation and assumptions and their review in a multiple circle iteration process. All assumptions including the erroneous ones are written into computer-based files for ongoing review and revision as necessary.



If one looks at all the strings attached within and around a conventional estimate, one wonders how a relatively unbiased estimate can be produced at all. If a big figure in terms of money, employment, technology and future of the enterprise is involved, it is fair to say that an engineering mind looks for varying results in estimating, typically a low, an optimum and a high figure. This would only be a true reflection of an open situation. Commercially educated people are usually horrified when more than one figure is presented and they will accept three figures only behind a comma. Parametrics provides for independent figures and for a bandwidth in the estimate that reflects reality in an engineering world. Where estimates vary to much, some serious questions are unavoidable and indeed necessary. Often Parametric Estimates are very uncomfortable surprises to the traditional setup. But this provokes the required discussion and throws opinions back to basic facts.

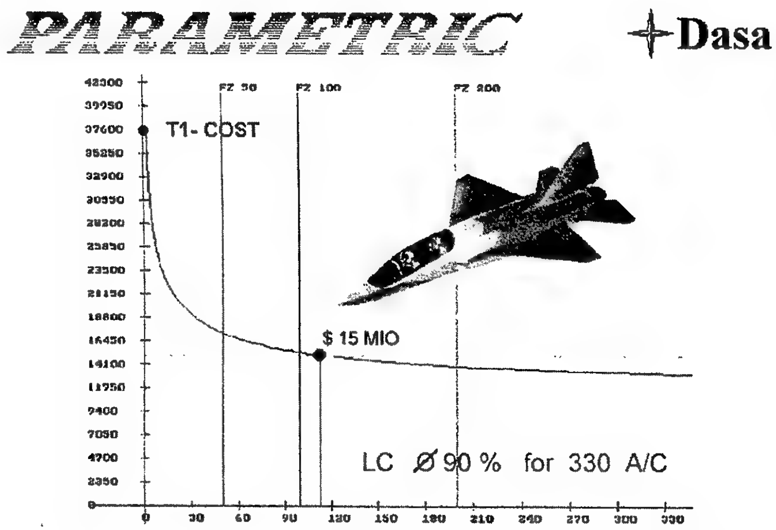


Parametrics provides for any essential detail to argue and settle the case. Often there are basic programmatic assumptions that vary greatly. When all important input parameters are discussed and understood equally well by all parties involved in the estimating process, and still major differences remain, it is highly recommendable to stick by the Parametric estimate. It provides a necessary yardstick to measure the projects by and might very well prove right in the long run. It is known that a wrong estimate is equally disastrous to the Project and its estimators.

PARAMETRIC

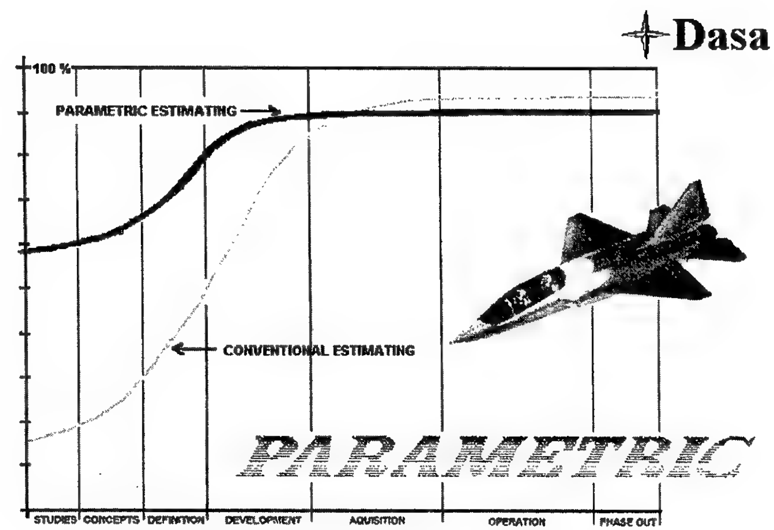
"It is the mark of an instructed mind
to rest satisfied with the degree
of PRECISION which the nature of
the subject admits, and not to seek
EXACTNESS where only an
approximation of the truth is possible."

ARISTOTELES



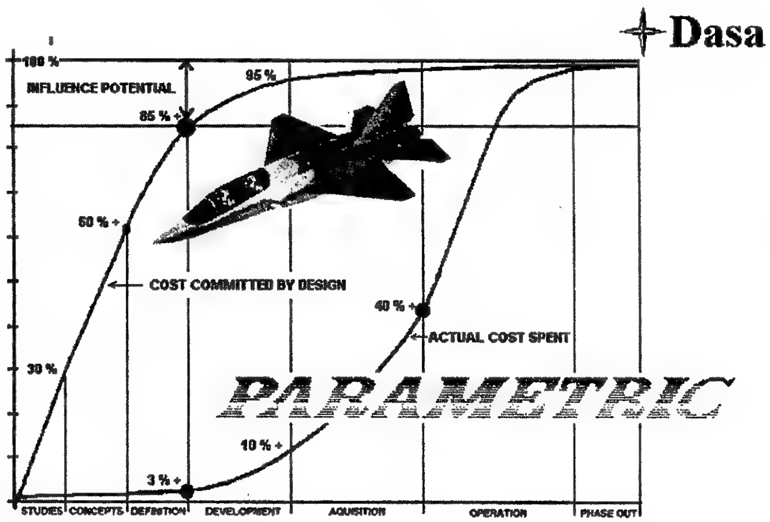
" LEARN " WITH THE OVERALL PROCESS OF PARAMETRIC ESTIMATING

All and any processes in nature – and engineering is part of the natural science world – travel on e-functions which differ very often dramatically from the linear, percentage type extrapolations which dominate the thinking of the typically educated commercial and business world.
Parametrics itself travels on curves, "learning curves", Time/Cost Optimum Curves, Confidence Curves, Maturity Curves on Technology, Curves on Cost Commitment, Curves on Cost-as-Spent, versus Cost-as-Planned.



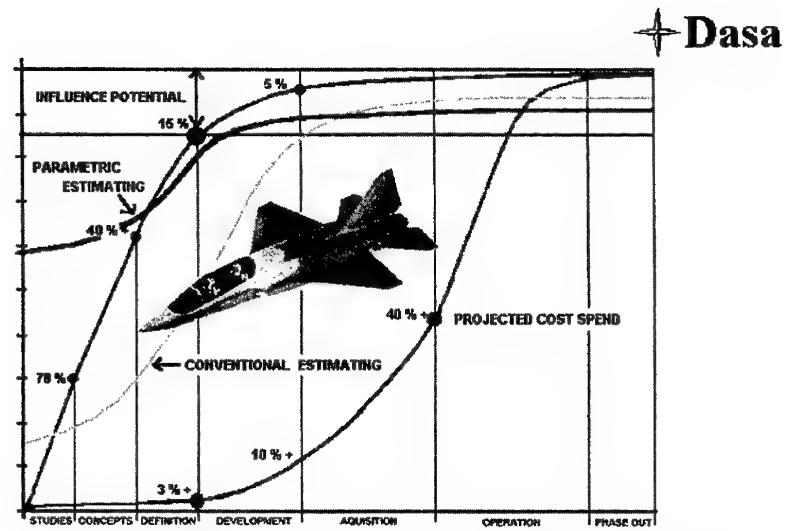
CONFIDENCE LEVEL IN ESTIMATING METHODS

Parametrics is known for working with very limited information in early programme phases, whilst the conventional estimating techniques require a great amount of detailed information to produce satisfactory results.



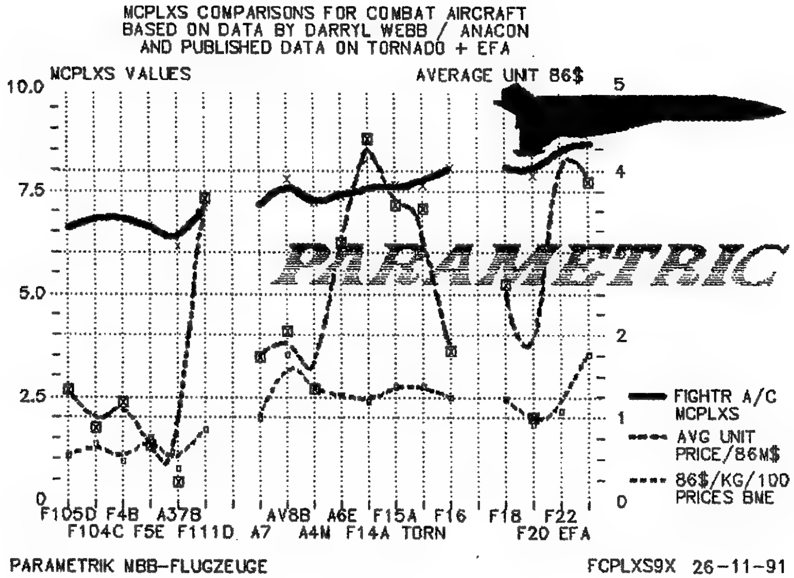
INHERENTLY COMMITTED COST DURING SYSTEM LIFE CYCLE

Already at the end of a system definition - with only 3% of the potential total programme cost being spent - more than 85% of all system life cycle costs have been practically committed. Costs for complex systems are inherently committed by performance requirements, configuration layout and technology used. Through very early estimates Parametrics can directly assist the layout of the project configuration, the performance tuning and the choice of technologies before real costs are being committed for the entire lifecycle of a system.



INFLUENCE POTENTIAL WITH PARAMETRIC

Now we combine the two sets of curves as above, namely the cost commitment and influence potential curve over the estimating confidence curves. We can reasonably conclude that Parametrics provides the essential estimates at the early phases of a project when all the crucial questions are being asked but only limited information is available.

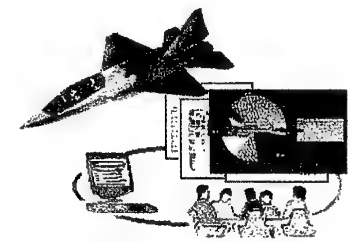


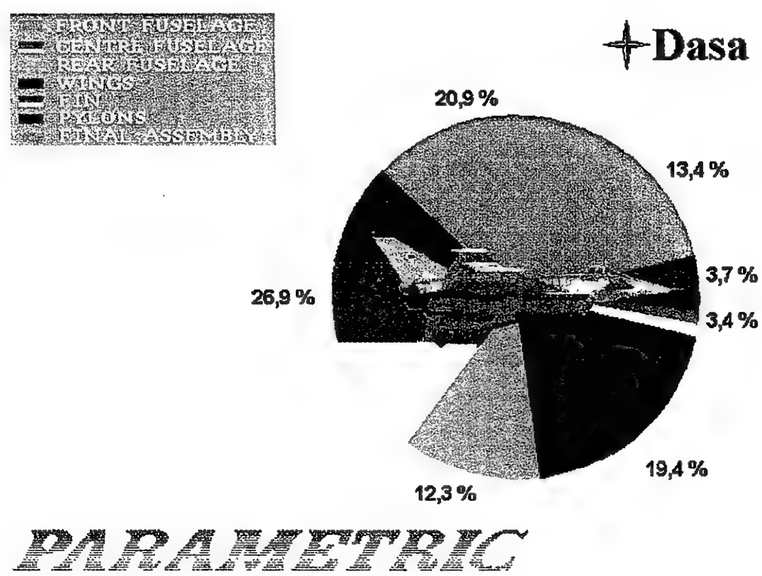
This chart gives a good presentation of the steady growth of complexity in newly developed systems. It illustrates at the same time that Parametrics can very realistically forcast technology trends and their effect on costs.

What is the credibility of Parametric estimates? There is more than 20 years of joint cumulative experience in the aerospace community. Most competitors in the US and European aerospace industry are using Parametrics in one form or the other. This joint experience is focusing in the existing models and procedures and provides for sound maturity of the Parametric estimating process.

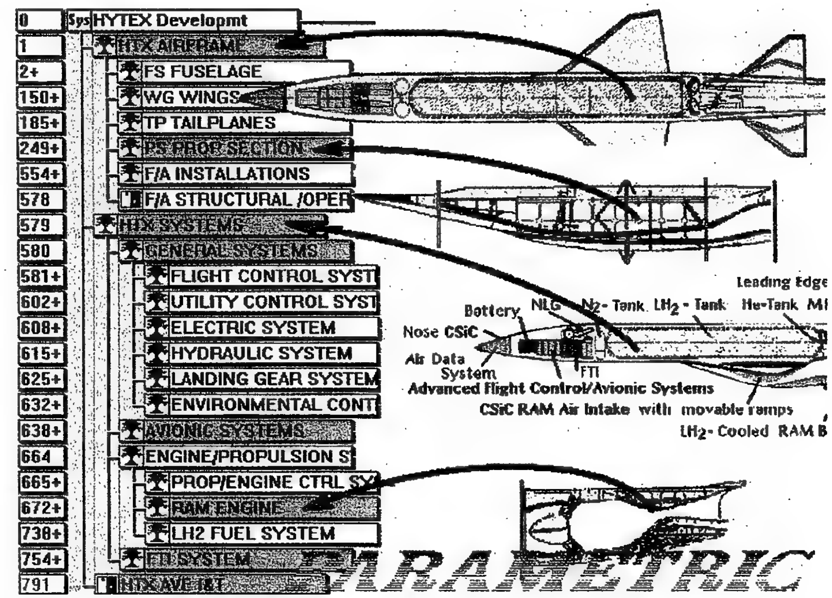
PARAMETRIC Dasa

- is presenting a neutral unbiased work sharing analysis
- is pulling isolated expertise and knowledge together
- is strictly oriented versus project systems and functions
- is almost unlimited in detail and structuring of projects
- is providing a very fast assessment on unknown technology



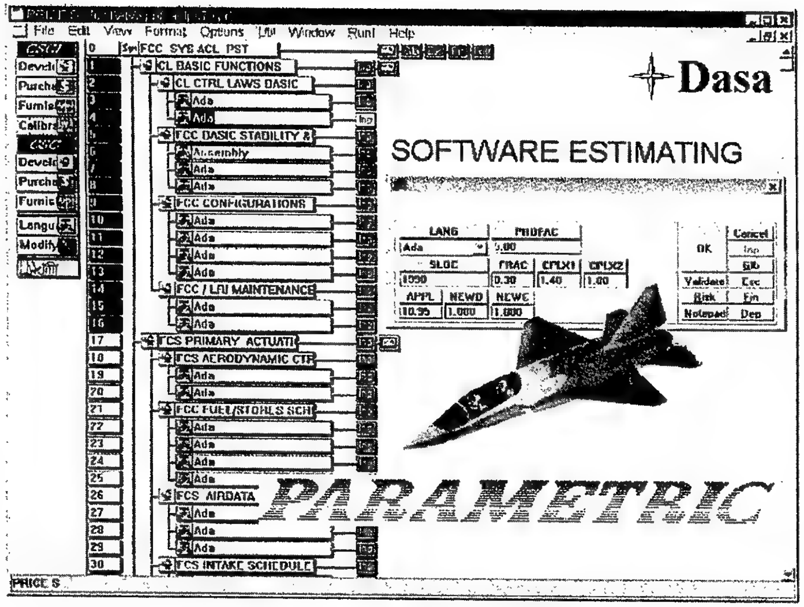


Parametrics assists complex work sharing analyses.

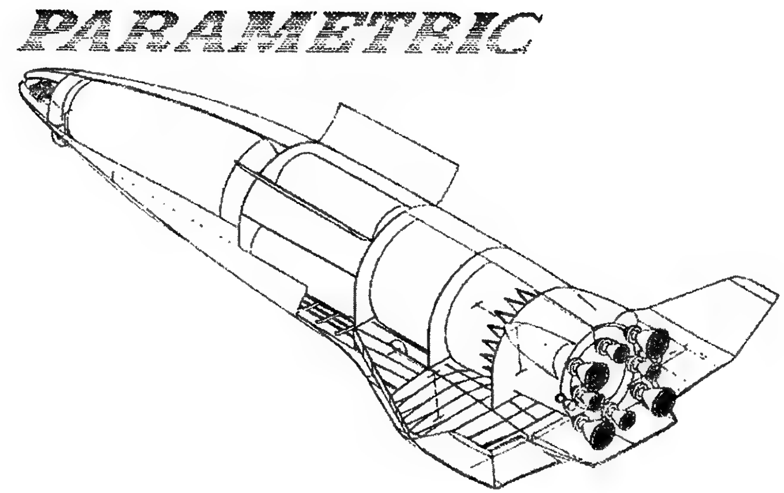


We translate the hardware configuration breakdown of systems into Parametric data files that completely reflect that structure. Any detail of a well defined programme breakdown is identified in this hierarchical presentation of the project and results in a perfectly product oriented Programme Work Breakdown Structure.

Parametrics becomes thereby a natural focus for a clear cut and thoroughProgramme Work Breakdown and stipulates the structuring of all engineering areas down to system and equipment level inclusive of software. Even though some definition may be highly fictitious for the moment, the data generated in the process will gradually start to fall into its natural place.



And we transfer software requirements into detailed estimates.



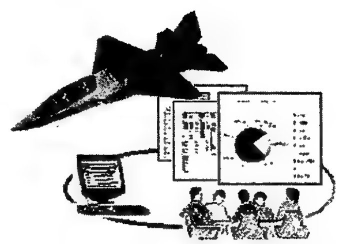
FESTIP CONFIGURATION STUDY

Parametrics as a methodology is at least commensurate with the subject it is dealing with and provides very fast assessments of yet unknown technology.

PARAMETRIC

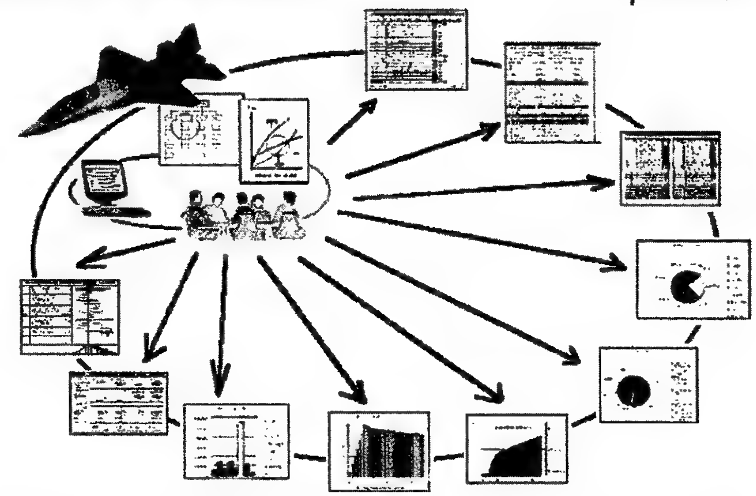
Dasa

is presenting data in digestible formats and graphs
is necessitating a clear Project oriented breakdown
is using history and experience in computerised combination
is forcing a rethink on traditional methods of working
is stipulating the crossfertilisation between projects



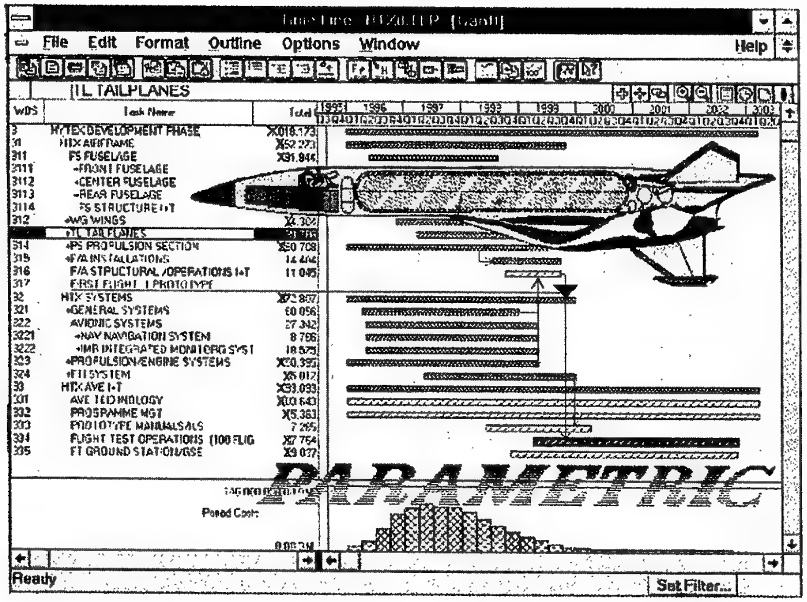
PARAMETRIC

Dasa



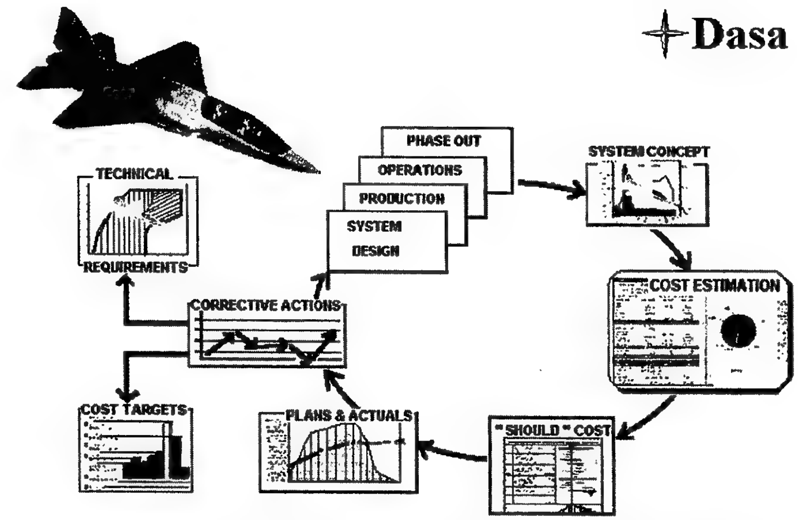
Project oriented digestible graphic and numeric presentation of outputs

Right in the middle of the engineering trade-off process Parametrics has become a focus for a clearly organised programme breakdown.



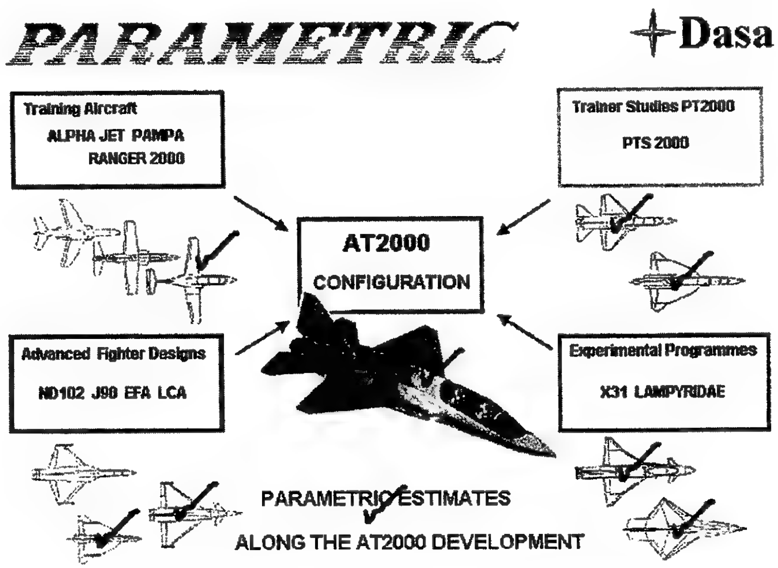
We present the cost estimate for all work packages along the hardware and software breakdown as well as the time schedules which the estimates produced for all the efforts in systems, equipment, airframe and integration.

Dasa



DESIGN - TO - COST PROCESS with PARAMETRIC

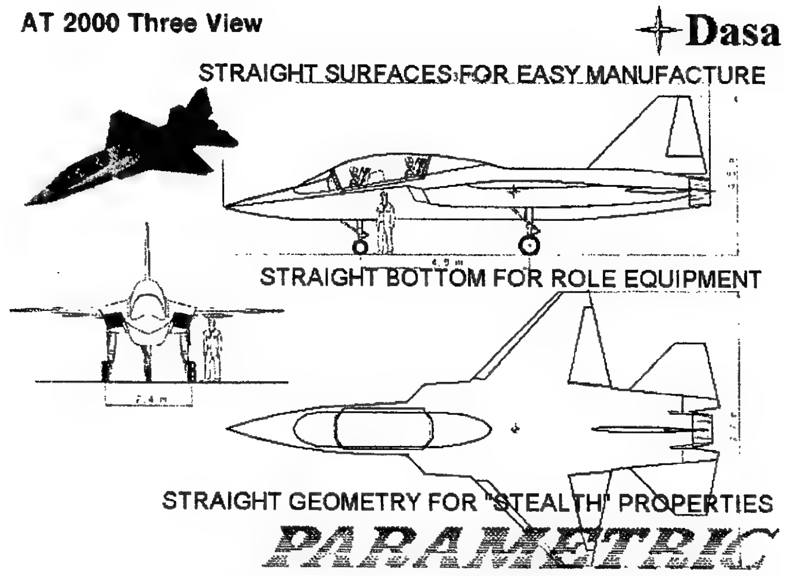
Not only in early project phases but during the whole iterative process of system design and development Parametrics can provide target costs and yardsticks for risk allowances, down to system and equipment breakdown level as well as regular cost-to-completion estimates to confirm or challenge the actual cost spending process and is, therefore, an excellent means in assisting project management with the design-to-cost and programme control processes.



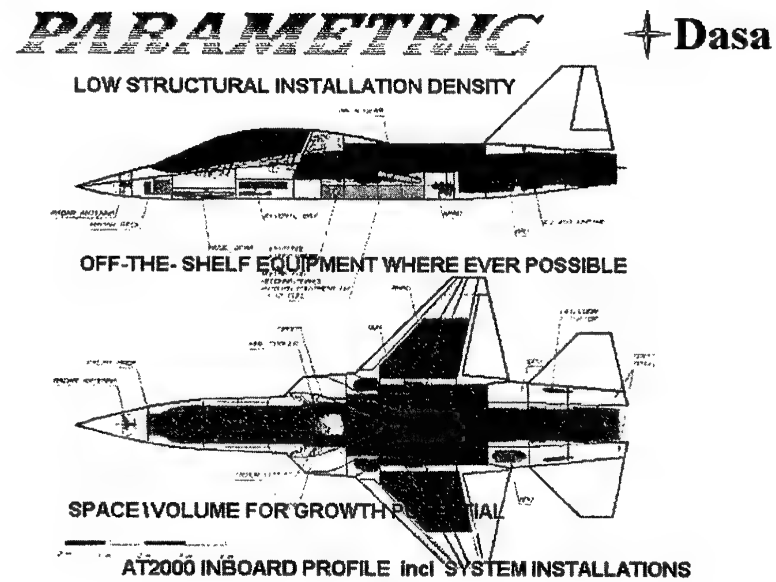
We have learned a lot on those previous projects in the last 10 years for better or worse. Strangely enough those very folks having learned their lessons best are usually being dismissed by a dynamic young new management in the very next corporate merger / reorganisation / mc-kinsense or what else that comes along named business reengineering, streamlining – lean management – product teaming – hierarchy reduction or any other of those "rain making" ceremonies.

"We trained hard... but it seemed every time we were beginning to form up into teams we were reorganized. I was to learn later in life that we tend to meet any situation by reorganizing, and a wonderful method it can be for creating the illusion of progress while producing confusion, inefficiency, and demoralization."

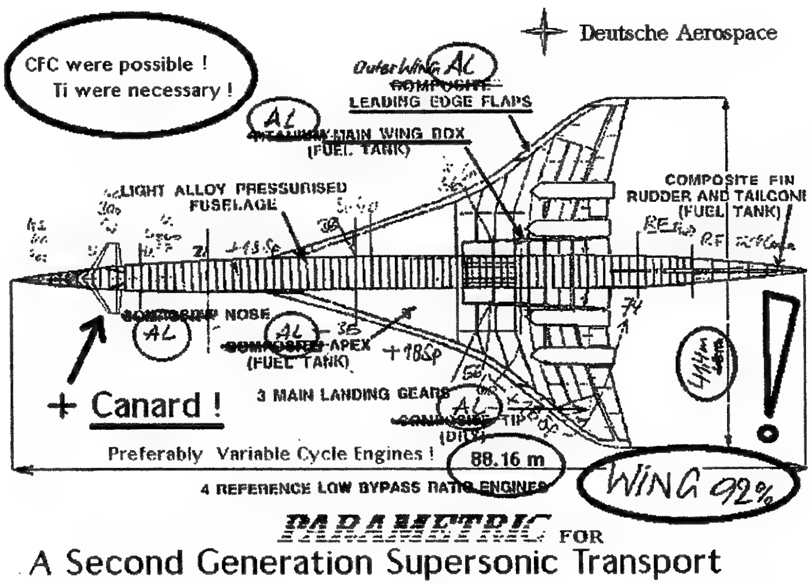
Gaius Petronius, a Roman Author
66 A.D.



And we will, therefore, continue to apply those lessons learnt to any and all of those actual projects that come along as applicable.



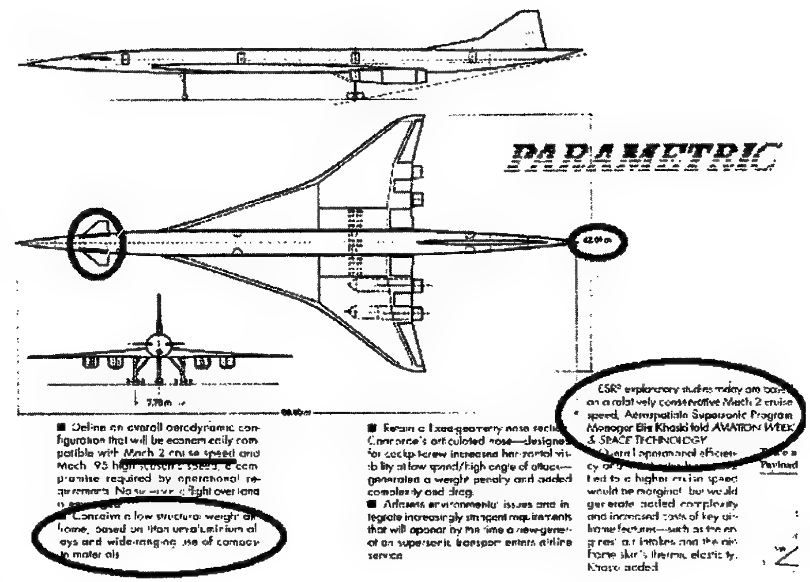
This recommendation holds very strong when affordability is the dominating configuration layout parameter. May be this is more of a challenge to engineering ingenuity than new technologies for a completely new subsystem and equipment development.
We in Europe have paid high prices for the parallel, interactive developments of airframes, engines and all individual systems and equipment. Interdependent developments are always cost drivers of an explosive nature.



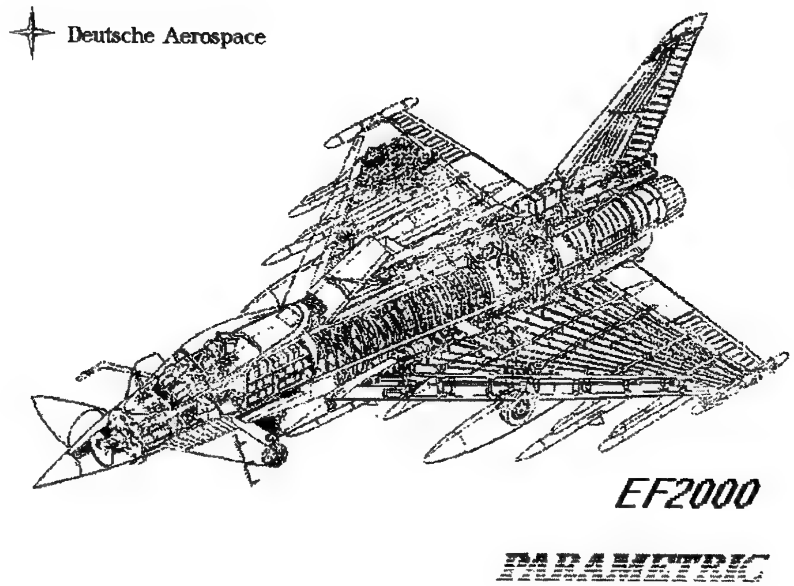
We reworked this big bird to reduce costs by almost half in making:

1. the design more flyable
2. the payload bigger
3. the range larger
4. the cruise speed lower

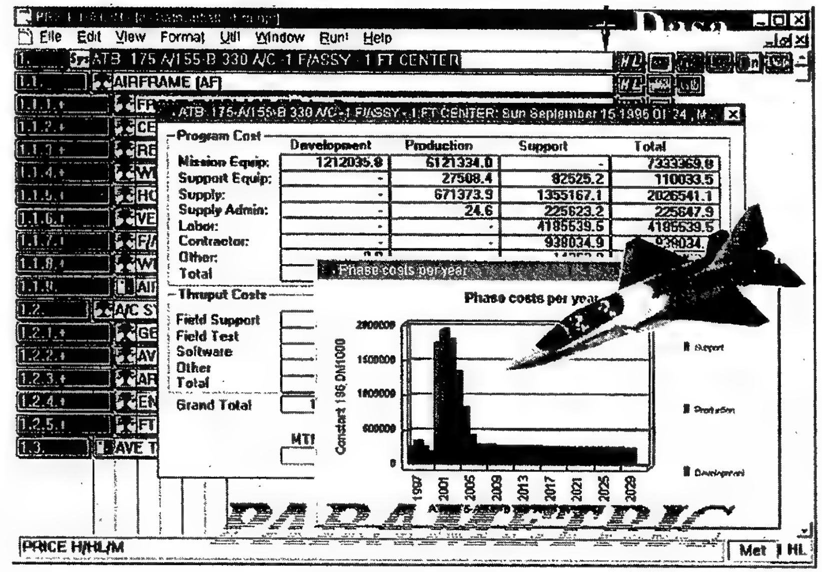
We added a canard, reduced the wing seize, removed exotic materials and technology and configured it as a MACH 2 instead of a MACH 2.4 airplane which transports passengers to the other side of an ocean only that half hour later, that is anyhow easily spent in border police, immigrations, customs or very similar international entertainment.



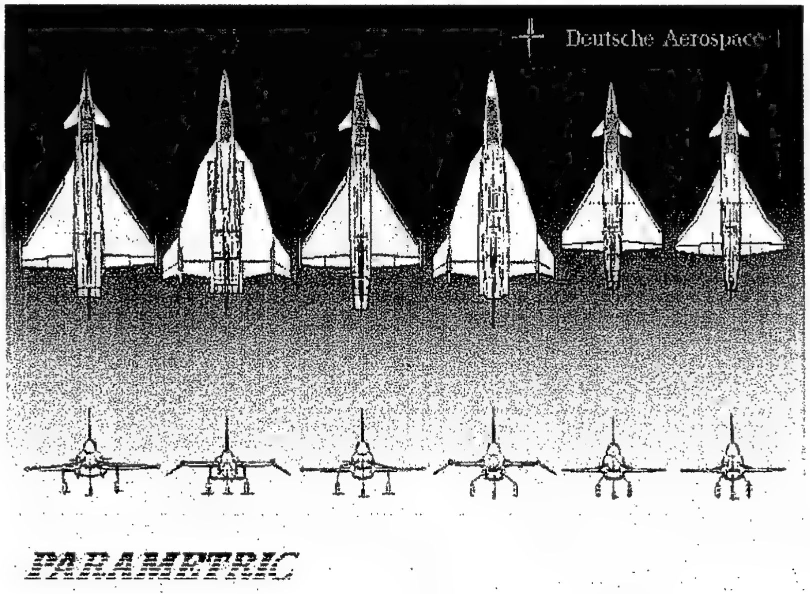
We were very glad to learn that – great minds think alike – i.a.w. Aviation Week & Space Technology of 5 September 1994 the design office of Aerospatiale stated the very same conclusions and the drawing published is almost identical to ours in the redimensioning of the previously proposed concept.



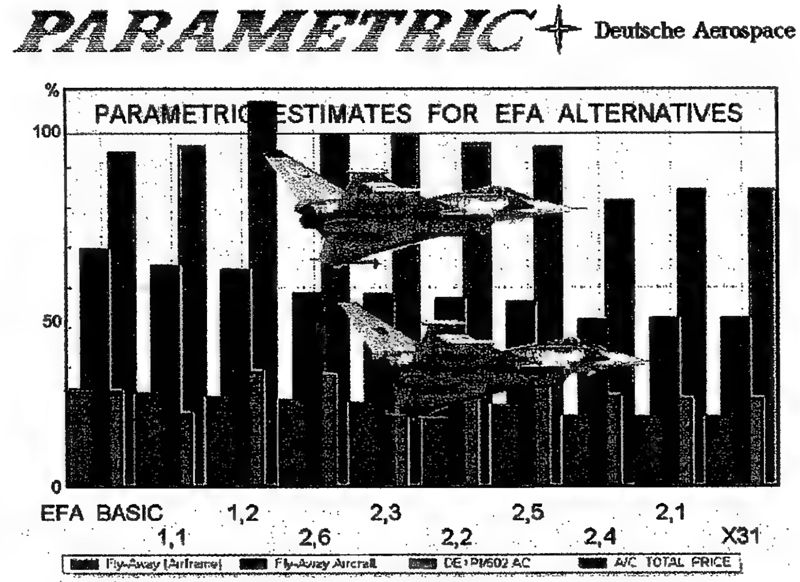
Some birds we saw on the drawing board in 1988......



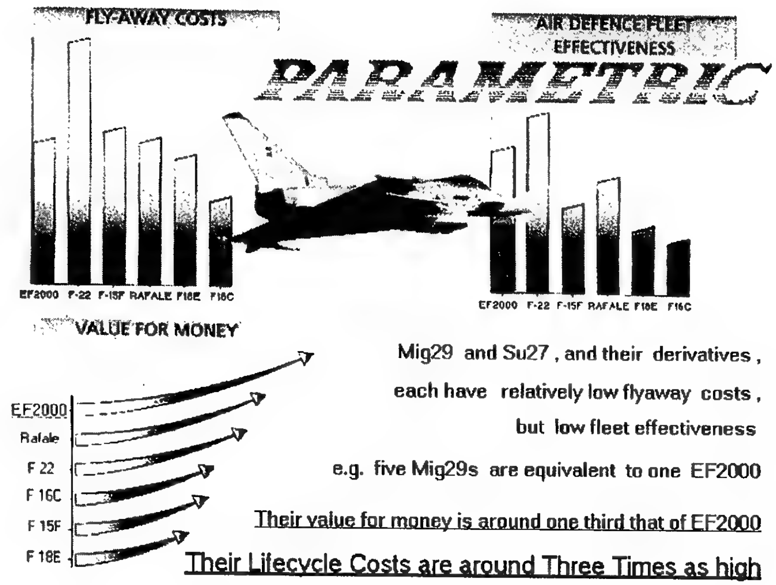
......through to life cycle estimates ......



.......and through to politically imposed studies of alternatives......

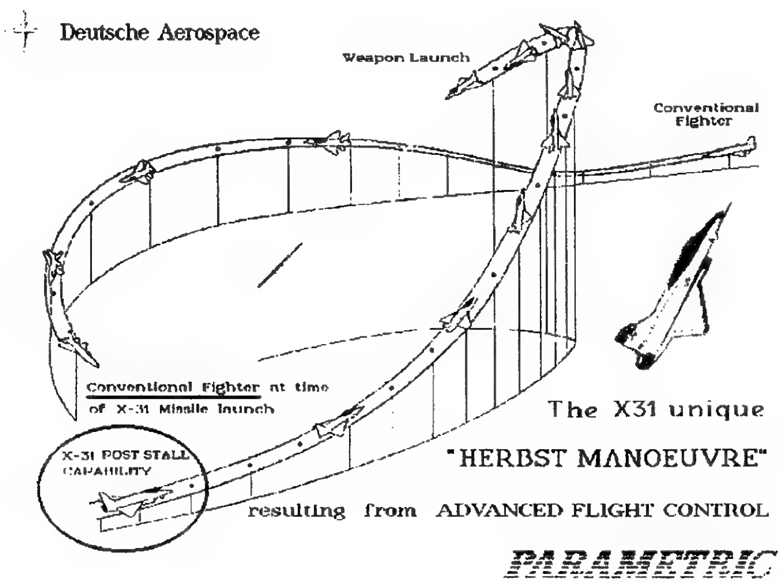


.....their respective cost estimates .....



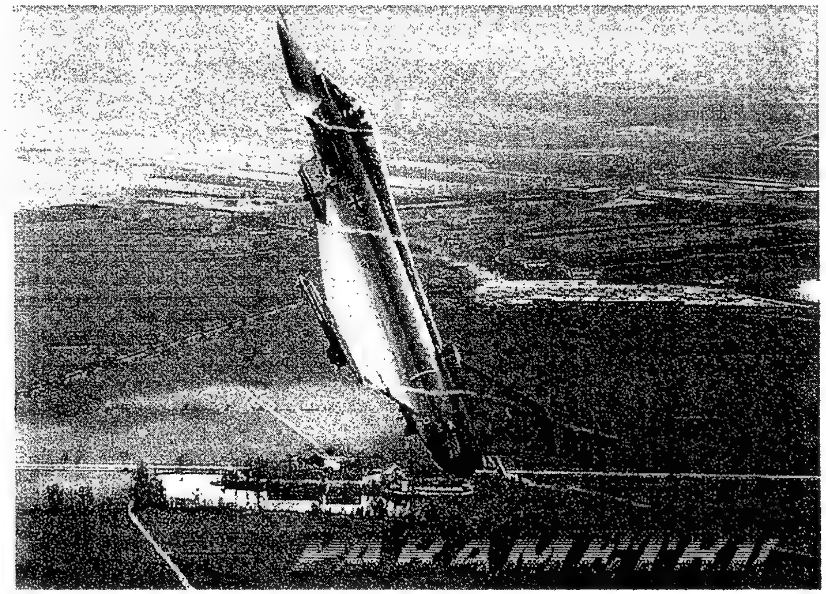
..... and finally through to all those system effectiveness studies!

What is known in the aerospace community nowadays as the "skunk works" principles, were really invented under second world war conditions, when, for example, the Heinkel 162 "Volksjäger" single engine jet fighter in 1944 went from drawing board to first flight in Vienna Schwechat in 6 months straight. The X-31 development in part took that approach but under peacetime conditions. And we can be proud of our involvement with an airplane that wrote aviation history in a most impressive way!

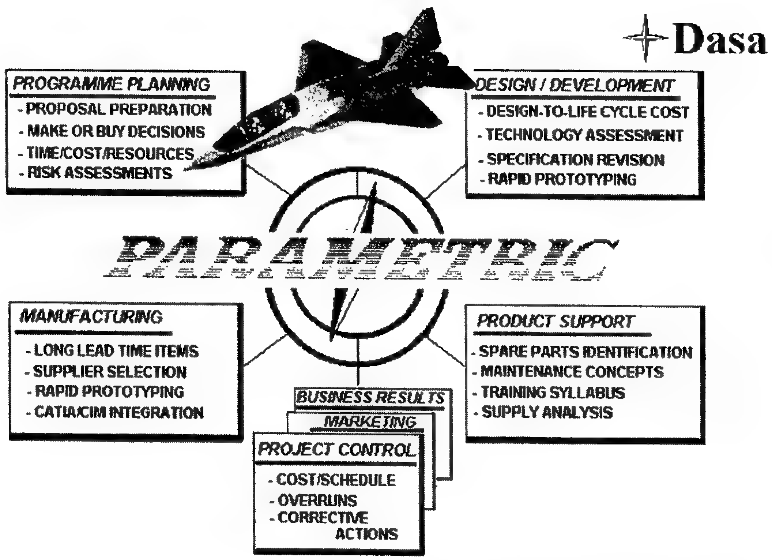


The late Dr. Wolfgang Herbst – an active pilot himself – was the inventor, designer and promoter of a concept for flying aircraft manoeuvres which eventually were named after him. Those manoeuvres are possible only in the post-stall regime, researched by the X-31 airplane in a joint American/German Programme at Dryden Airforce Base. We have modelled the costs parametrically.

In dogfights actually flown with camera and computer recordings against the most modern fighter airplanes in the US inventory the X-31 exceeded with a "Kill"-ratio of 11-to-1 all predictions. These dramatic manoeuvres are revolutionising aviation once again and are necessitating a major rethink of modern air combat tactics. And obviously the cost implications are being asked for. And they are all-in-all very favorable.



The opportunities offered by this technology jump makes it obvious to apply the lessons learned to most of the modern fighter airplanes like in this computer scenario. Parametrics is doing the cost estimating for various advanced concepts.



COMPASS IN A WORLD OF UNCERTAINTY

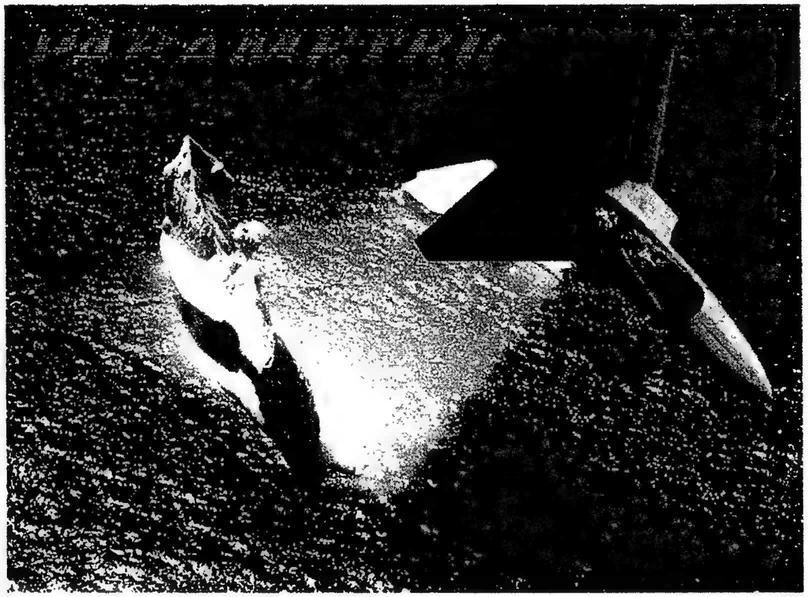
Computer Assisted Parametric Estimating ("CAPE") – there is no doubt – is the technology of estimating for any foreseeable future. It is time now everywhere to rethink all internal procedures with the aim of coping with the dramatic changes of most industrial processes which confront the first and second world countries in view of the needs of the so called 'third world' representing more than 70% of the world population. It is named globalisation. To justify our earnings, wellbeing, profits and prices we need more proficiency, more productivity, more profitability, more efficiency in comparison to our present industrial and administrative processes.

This applies in particular to the huge governmental and administrative bureaucracies. The perfectionism of these bureaucracies is inversely proportional to the affordability and maintainability of systems, products and services they demand. And that includes "green issues" as well.

But high-tech is indeed "the" technology motor both for industry and ecology to initiate the necessary changes which are desperately needed but do not flourish very well in the present administrative climate. It is because of ignorant economical and commercial dominance that a technology with a clearly superior and ecologically favorable impact is not properly taken into account. This bill will be presented later.

Aerospace with its high-tech environment is at the top of the challenge. It has a lot to offer. Parametrics is a product created by the aerospace community. This implies responsibility.

I think there is every chance to efficiently reengineer all our internal governmental and industrial procedures and processes. Parametrics can at least be a compass in a world of uncertainty.



Parametrics keeps a close eye on the iceberg named "future". Not with a prophecy but with a cool and balanced engineering judgement. The future remains like an iceberg. Only limited parts show their size but with Parametrics at least some better view can be taken of it.

The IPF Project —
Concurrent Engineering Efforts at Kongsberg Defence & Aerospace

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SUMMARY

This paper describes Kongsberg Defence & Aerospace's (KDA) work in the implementation of Concurrent Engineering (CE) practises. The work has been done through an internal improvement project, IPF.

The paper provides information about background, methods, tools, supporting techniques, verification examples and results. It documents results showing that adaptation of the CE practises can lead to a tremendous savings in project cost and time.

1. INTRODUCTION

Because no two companies have identical work environments or organisational structures, CE cannot be implemented in one company by use of a general method, but must be incorporated with leadership focus on the company's individualities.

To clearly describe the CE efforts and results at KDA, we find it necessary to provide a brief description of our organisation, infrastructure, products and professional capabilities.

1.1 Kongsberg Aerospace & Defence Organisation, Projects and Products

KDA has approximately 750 employees and is a company within Kongsberg Gruppen ASA. KDA is one of the leading high-tech industrial groups in Norway. The development and production of missile systems have provided technology which is now applied in space- and aviation-related product areas. Our activities also include development, production and maintenance of command and weapons control systems for the army, air force and navy, as well as tactical communications and tactical trainers.

In addition to the new Anti-Ship Missile (NSM) development program, described in Paragraph 1.2, some of our current projects include:

Ariane 5 KDA has developed and manufactured the attachment and separation mechanisms for the boosters on Ariane 5.

M-ADS The Modified Automatic Dependent Surveillance System is a new surveillance system for helicopters operating in North Sea sectors without sufficient radar cover.

Penguin The Penguin Anti-Ship Missile is a passive, infrared homing, fire-and-forget missile for use against surface combatants and support ships, day or night, including during adverse weather conditions. The missile is available for a wide range of platforms.

More information about Kongsberg Gruppen ASA is available on Internet at http://www.kongsberg.com.

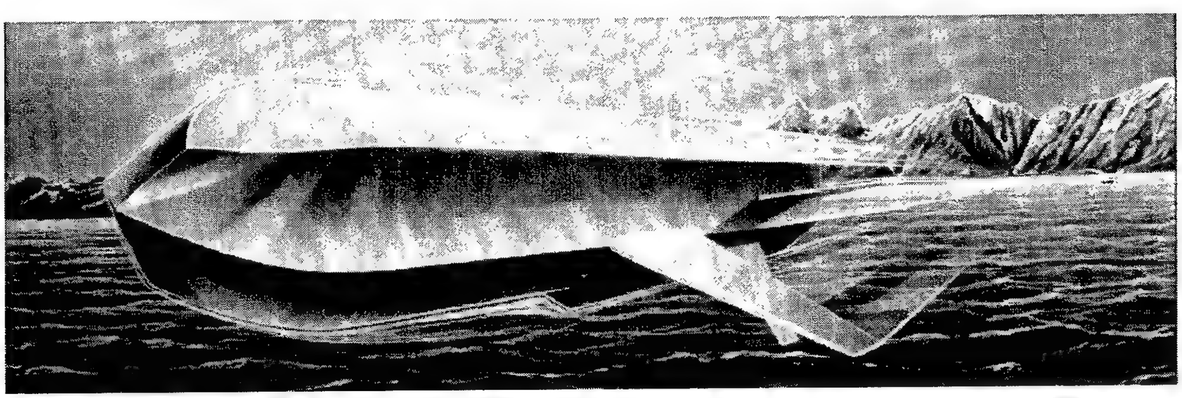

Figure 1 An artist's impression of the NSM Missile

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

1.2 The new Anti-Ship Missile (NSM) System

The Royal Norwegian Navy has selected the NSM as their next generation anti-ship missile system. The NSM missile is based on the extensive expertise gained from development of the different versions of the Penguin missile. The NSM, now in full-scale development at KDA, is a flexible anti-ship missile system easily adaptable to a multitude of weapon platforms, such as FPBs, frigates, mobile coastal artillery units or aircraft. In addition to the missile itself, the missile system consists of a missile system administrator and launchers.

The NSM represents the next generation of medium range, low-signature cruise missile. The missile will be autonomous, highly manoeuvrable and will have low signature and weight. The missile's highly accurate multi-sensor navigation system ensures target detection and provides flexibility of trajectory shaping via automatic or operator-designated way points over land as well as sea. An artist's impression of the missile is shown in Figure 1 and the preliminary data for the missile is given in Table 1.

Table 1 NSM Preliminary Data

Length	4.2 m
Wing span, unfolded	1.4 m
Wing span, folded	0.7 m
Weight with booster	420 kg
Warhead	120 kg
Propulsion	Turbo-jet
Terminal guidance system	Passive Infrared
Cruise speed	High subsonic
Operational range	> 100 km

1.3 Areas of Competence

The complicated process of designing a new missile system requires a staff with thorough technical knowledge in several professional disciplines. Actual delivery of the missile system requires of KDA the capability of specifying, designing, analysing, manufacturing, assembling and testing complex composite/metallic structures, electronics, electromechanical units and software. Our employees have the necessary expertise in a wide range of skills:

System-design	Aerostructures
Cybernetics	Mechanics
Electronics & cabling	Electromechanics
Software	Simulation
Process development	Manufacturing (metal, composite, electronics, cabling)
Assembly	Test and verification

Manufacturing and assembly are partly performed in Kongsberg Business Development & Production, another part of Kongsberg Gruppen.

1.4 Infrastructure

The engineering and manufacturing departments are equipped with state-of-the-art tools, as, for example, 3D M-CAD/CAM (Euclid 3), E-CAD (Mentor Graphics), Mechanical analyses (MSC/Patran & Nastran), Computational Fluid Dynamics analysis, Object-oriented SW development tools (ObjectTeam, ClearCase) and CM/MRP systems.

The NSM project has developed its own simulation system, SIMEN, which is presented in a separate paper.

1.5 Reasons for Improvement

Although we are a very competitive supplier in our manufacturing fields, we have needs, for internal and external reasons, for development and improvement.

1.5.1 External Issues

The external pressures on the aerospace and defence markets have risen significantly since KDA performed its last large missile development (during the cold war). The defence, aerospace and aviation markets demand cost-effective development and production at extremely high quality and competitive lead times. A competitive company in these markets continuously needs improvement in organisation and working methods. For KDA, with employees working in various areas and with the tools described above, this is a big challenge. Budgets have been reduced and the frame of business performance has been changed from cost contracts to fixed-price/shared-risk contracts.

1.5.2 Internal Issues

The main cause for improvement has been to achieve rapid and low-cost development and production of the NSM missile system. The IPF project therefore should give short-term results for NSM, while also affecting other existing and future projects in KDA. The traditional methods of product structuring and performance haven't been suitable for a new, large project like NSM with its time schedule and cost restraints.

KDA has experienced many of the problems normally associated with weapon system design, with numerous faults appearing late in the development of the product, some even after the product has been accepted by the customer. The costs of the faults at times have been great, sometimes even requiring requalification of the product.

We knew that we had many areas for improvement in our development and manufacturing at the start of the IPF project, some proving more of a challenge than others. Some of the indicators which we identified early were:

- Faults as indicated above.

- Co-operation and communication between departments/personnel were inadequate.
- Reuse of information between numerous computer systems was insufficient.
- Useage of the IT tools was insufficient—the processes were not modified for full benefit of the IT tools.
- Our infrastructure was not suited for massive use of IT—we only controlled parts of the electronic information, e.g., the document title and not the electronic document itself.

In 1995, the manager of the Penguin Business Unit attended a Master of Technology Management program at the Norwegian Business School/ Norwegian university of Science & Technology (ref. [Sand96]). A typical production program—which was also our last large production program—was subjected to his program work. All changes which had occurred after the product had been approved by the customer, at the qualification approval date, were subjected to a detailed study. The information given in the Engineering Change Orders (ECOs) (a total of over 1000) were analysed, decoded and fed into a database

The main causes for change were:

- Inadequate Analyses performed
- Inadequate testing and/or Inspection
- Misprints/omissions
- Insufficient communication between development departments
- Insufficient communication between development and production departments.

It was evident that engineering changes could have been avoided by better communication and co-operation in the development phase. And since the cost of fixing errors discovered late in development or production are significantly higher than in the early stages of product development, the necessary improvements would have reduced project costs significantly. The goal is to avoid these changes and move most of the ECOs to the early phases of the development program.

1.6 Improvements

Implementation of CE appeared to be an answer to the challenges we are facing with a complex technology and project, and a multi-skilled staff. We therefore started a preliminary study to define CE and its implementation, and allocate funding.

This implementation is part of the continuous improvement process within KDA, and started as a part of the approval by the Board of Directors of the 1994 strategy plan. KDA has been organising the improvements in steps. The two large improvement efforts before the IPF project were:

1. Change from general production to cellular production.
2. Change to product-oriented organisation. The . centralised development department was broken up and distributed to the business units.

From the beginning of the implementation of improvements, it was vital to create ownership for the CE concept in upper management of KDA. It was also necessary that CE be employed by our "customer", the NSM project and the functional line organisation. This proved to be difficult at the start, be we eventually succeeded.

1.7 CE, IPD, IPPD and IPF

CE can be defined in many ways. KDA uses the following definition:

"Concurrent Engineering is a systematic approach to the *integrated, concurrent design of products and their related processes, including manufacture and support*. This approach is intended to cause the developers, from the outset, *to consider all elements of the product life cycle* from the concept through disposal, including quality, cost, schedule and user requirements". [IDA88]

Integrated Product Development (IPD) and Integrated Product and Process Development (IPPD) are newer terms describing the same issue.

The individual organisation has to establish its own interpretation of CE—what it is, what it means to us, and what we should focus on. Universal answers do not exist, making implementation of CE a complex task. Due to the various definitions, we gave CE a Norwegian name: *Integrert Produktfremtaking* (Integrated Product Realisation). To indicate that CE involves development, production and other manufacturing areas, "Product Development" was replaced with "Product Realisation".

1.8 Overall Objective

The overall objective of the IPF project is to reduce cost and risk throughout the life cycle of KDA's products. We have broken this objective down into the smaller elements listed in Table 2.

Table 2 Expected results after the IPF-project

	Cost-effect
Faster/better development	–20%
Use of more resources earlier (more time spent earlier in the development phase than before)	+5%
Reduction of costs of changes in the development phase	–50%
Reduction of costs of changes in the production phase	–25%
Reduction of production cost	–10%

2. INFORMATION ABOUT THE DIFFERENT PARTS OF THE IPF PROJECT

The project was broken down into three major subprojects.

a. **Working methodology**

b. **Computer tools**

c. **Infrastructure (renamed Product Data Management)**

These subprojects are described thoroughly below and are visualised in Figure 2. They are means of ensuring that the product fulfils a set of demands where customer expectations and requirements are the most important (i.e., the product and customer are in centre).

In the project, it was necessary to improve the way people interacted. To achieve this, we defined the subproject called "Working Methodology" (refer to Paragraph 2.1). To use computer tools better, we created a subproject for handling them (refer to Paragraph 2.2). We also realised that we did not have the proper infrastructure to support the projects and teams. For this need, we created the subproject "Infrastructure", later renamed PDM as the tool selected to support the teams and provide improved use of the IS and IT tools (refer to Paragraph 2.3).

Even though two thirds of the IPF project was about IT tools, the tools are only for support. The main purpose was, and remains, to change the way people interact. In fact, much of the plans from the beginning of 1995 have not developed according to expectations. Nonetheless, the main concepts which we defined in the beginning are still valid.

2.1 Working Methodology

Like Boeing (ref. [Sabb96]) and other companies, we had two options for solving complex, time-consuming tasks with long time duration:

1. Create super engineers who independently know about all details of the complete life cycle of the parts/software which they work with.
2. Work together with a selection or team of individuals who, in co-operation, have the detailed knowledge of the complete life cycle of the parts/software they work with.

With option 1, many of our personnel might become generalists, losing their specialist skills. Option 2 has seemed a wiser course, but it has not been easy to transform the organisation from a *functional oriented* project organisation into a *team-based* project organisation in which the participants have respect for and confidence in the competency and skills of their team members. We decided that teamwork should be a central part of our project.

Thus, the interface between the work that is done on each of those components becomes critical, and the concrete ways to cope with such critical interfaces becomes crucially important. It is easily seen that cross-disciplinary communication between people who posit different technical skills and who interface with each other is of great importance.

We realised that, in addition to the implementation teamwork, we had to document and improve our best work practise (refer Paragraph 2.1.2). A contributing factor was the work we did to create an IS/IT-strategy (refer to Paragraph 2.4).

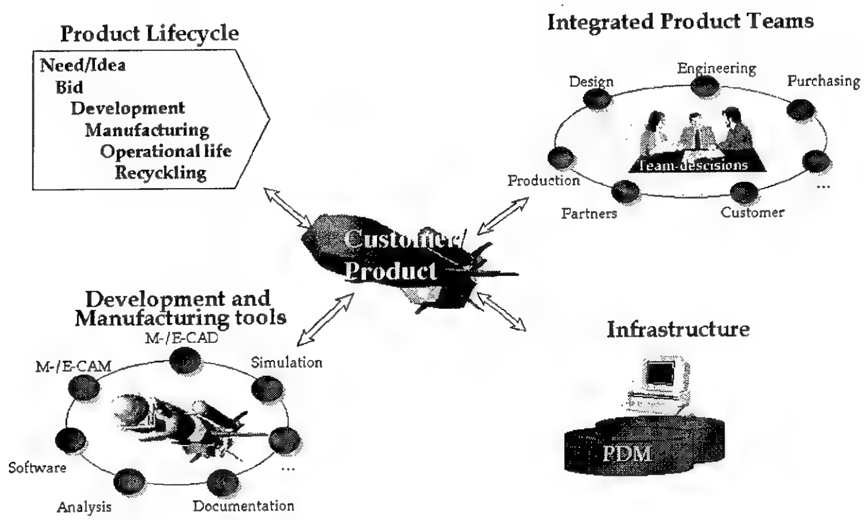

Figure 2 Vision of the IPF-project

The teams also needed support techniques for performing their tasks. We had used a lot of these earlier, but the IPF project introduced both new ones and structured ones already in use. The techniques could be used for creating a good cross-functional work in the teams, e.g., operators in conjunction with engineers evaluating production and assembly aspects of a design early in the concept/preliminary design phase - Design For Manufacturing and Assembly, DFMA. One of the supporting techniques introduced are described later (refer to Paragraph 2.1.3).

2.1.1 Cross Functional Work/Teams

To speed up the development process and involve the right personnel at an early stage, we have identified the need for cross-functional Integrated Product Teams (IPTs).

We have had some experience with teamwork, as for example, the development of the composite wing for the helicopter version of the Penguin missile in which production people participated in the early design phase. During other examples, when we encountered significant problems in series production, IPTs were established as multi-skilled problem solving teams. Without exception, this has worked out very well and is a sound support for establishing such teams in the design phase.

The following results are expected when working with IPTs:

- Better technical solutions — the products are optimised for a broader set of functions/professions and the complete life-cycle.
- Production and user-friendly product.
- Reduced costs of errors — changes are made to the product early (when costs are low) in such a way that we have either no or negligible changes/problems/ waivers late in the development or production.
- Improved motivation for the product in the whole organisation.
- Increased creativity.
- Reduced time to market (more activity in parallel; concurrency).
- Reduced cost.

The team organisation is more dynamic than the rest of the project organisation. A team exists as long as it has a task to perform. After its function is completed, it is dissolved. An extremely dynamic organisation is new to our employees and, therefore, requires some time before they feel comfortable with it.

An IPT consists of individuals with different skills depending on the task required. Although the IPTs may not always be cross-functional, they will be organised nonetheless according to the task. This is illustrated with the two-dimensional diagram in Figure 3 in which the teams are organised in one or both the dimensions of professional discipline and life cycle.

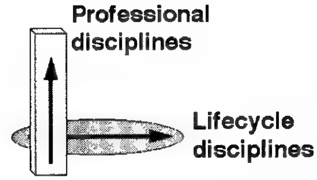

Figure 3 The two dimensions of teams

Professional disciplines: The team consists of individuals with expertise in at least one of the different professional disciplines needed for the task; e.g., systems, SW, cybernetics, aerodynamics, mechanics and purchasing.

Life cycle disciplines: The team consists of individuals with expertise in a life-cycle discipline of the product; e.g., system design, mechanical analysis, design, engineering, process, operator, purchasing, customer, partner.

The tasks given to the team are typically either to solve technical issues/problems or to co-ordinate work done by other teams.

Organisation of projects

KDA projects are typically subdivided like the product breakdown structure shown in Figure 4. The subprojects typically consist of teams based on life-cycle disciplines and cover all professional disciplines needed to develop and produce the product parts the subproject is responsible for. When it is necessary to optimise the complete product and not the product parts, KDA will staff an IPT with personnel selected from across the subprojects giving the team a professional discipline base.

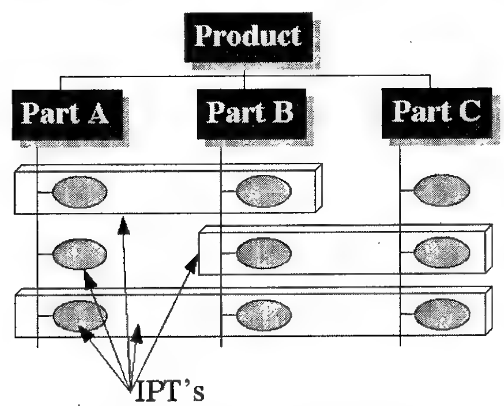

Figure 4 Product breakdown versus teams

IPT: Responsibility and Authority; How to Succeed

If an IPT is to function well, it must have responsibility and authority. The team-members must have a positive attitude about the team and actively support the other members. They must fully understand what is expected of the team. The leaders must have confidence in the

methods of integration and cross-functional work, and be able to build enthusiasm and spirit in the team.

Attitude is equally important for team members. Each member must know why he or she is in the group. In addition to being technically competent, the members must be committed to the group and actively participate in group matters.

IPTs should be staffed with the right personnel at the right time. The teams must help to define the resource needs. The goals for an IPT should be realistic while the expected results should be defined unequivocally.

The task mandate must be co-ordinated with the IPT principal, i.e., the person to whom the team leader reports. The IPT will perform trade-offs and evaluations, and recommend solutions. Although the project management will decide the major decisions, the IPT will resolve minor issues and find solutions to their task.

2.1.2 Improving Business Processes

Due to the high technical complexity of the tasks of developing and manufacturing our products, we have introduced processes. These processes describe in a schematic way the various steps in development through which the particular components have to proceed to ensure that the various parts of the missile system are in accordance with the customer requirements and KDA's best practise. The following processes have been described and released (first issues):

- Project management
- Product life-cycle management
- Contract definition/concept phase
- Product development
- System development
- Mechanics development
- Software development
- Electronics development
- Printed circuit board development
- Electromechanical development
- Approval, updating and modification
- Acquisition

Other processes have been identified and will be implemented in the future.

Process-Outline:

A process typically consists of a set of elements:

1. General information such as owner, approval authority, references, objective and scope.
2. Schematics showing activities, dependencies, plans, etc.
3. Detailed descriptions:
   a) Activity sequence
   b) Activities which shall/should be performed to develop the specific unit/part
   c) Participant in the process (Actor)
   d) Responsibilities and tasks for Actor

Table 2 Example of detail process description

Actor	Task	Comment
HDS-resp. (editor)	**Draft of Hardware design Spec. (HDS)** Writes an HDS draft which is sent for technical review *Objective: Control identified requirements Participants: System, SW, Safety & reliability*	HDS-template
	User meetings Informal meetings with users to discuss issues related to the spec. *Users are ...*	
HDS-resp. (editor)	**Consultative Design Review of HDS** Review of HDS Purpose... Participants...	Procedure INS-0072 Checklists
CM resp.	**Design Review of HDS** The HDS is released (revision –)	

2.1.3 Supporting Techniques

Improvement of software development, one of the process techniques introduced to our manufacturing, is described following.

Improvement of the SW development process—SW error registrations

Our success rate has been very good in design, development and test of SW with negligible errors in the released SW. But we have wanted to investigate all areas, including those where we have had success, to see where improvement is needed. After we discussed the process with our SW engineers, it was clear to us that the time before delivery had been rather hectic such that a thorough examination of the development process was warranted.

The earlier opinion of our development engineers was that a product is finished when it is released with the revision status, *Revision –*. Modifications and changes to the product prior to release was thought to be an integral part of the development work. Rework, defined as "when a finished task requires modification/change", was introduced to characterise the errors and changes to the SW prior to the released version.

In one particular study, using this definition, we looked at recorded data from a typical project where SW had received a large portion of the overall budget. The errors and changes were sorted according to IEEE standard P1044/D6 (draft), ref. [IEEE]. There were the following categories of recorded data:

- Error id
- Error class
- System
- Unit
- Phase introduced
- Phase found
- Time to correct

The data showed that although the errors and changes were found in the SW integration phase, they were introduced in the design and coding phases. It was evident that if errors could be found in the phases when they are introduced, much time and money would be saved. There were various causes of the errors:

- misunderstanding of requirements
- poor communications
- carelessness in coding
- modifications of requirements from the customer
- improper project plans
- incomplete reviews.

The recorded data indicated that about 20 percent of the SW development cost is used for corrections of errors and implementation of changes to the system. According to available information, other manufacturers are as high as 40 percent for rework costs.

2.2 Computer Tools

Being a relatively large company, KDA has been using numerous IT tools in development and production of parts and SW. These system tools must be used in effective ways, e.g., the business process must reflect the advanced information systems used and the information created must be available for the IPT members. We looked at all the tools used in the design and production of parts and software. The objective of the study was to find out how well KDA scored in the following three concerns:

1. Do we have the tools we need for the NSM project?
2. Do the tools communicate properly?
3. Do we use the tools as effectively as possible?

The results of the study showed that we need much improvement in all three areas.

2.2.1 What We Have Done

The requirements for fulfilling specific tasks, as for example, our requirements regarding production "documentation" of electromechanical parts, were defined as a result of this study. We identified several new systems for solving these tasks and implemented them in the organisation. Several interface programs were also implemented.

Regarding use of the systems, we thoroughly analysed how our employees used the systems to create the desired information. It was evident that many of the systems were used in outmoded ways. The main output from our 3D-CAD-system were paper drawings with many measurements and not 3D models. Although it was suggested that this was a result of our internal procedures, it proved not to be, surprisingly. In fact, all the unnecessary detailed documentation was due to the old habits of the individuals.

2.2.2 Some results

We have reduced the number of drawings by approximately 75% and now base our production and development more heavily on the information in the 3D-CAD models

We are now able to have a *complete* electronic model of the missile system with real-time electronic review with collision detection and animation.

2.3 Product Data Management (PDM)

In such a complex environment as KDA, it is necessary to have a effectively functioning infrastructure for supporting the team members, handling information and controlling all the computer systems needed for delivering our products. It became evident that PDM was the right tool for us, even though it might seem a bit drastic to use such complex systems in a relatively small business as KDA.

A PDM system, from Sherpa Corporation, will be implemented to manage all the product-related information throughout the product life cycle. In contrast with most PDM vendors which deliver a building kit, Sherpa has a "turn-key" application called Integrated Product Development (IPD) which is designed by Sherpa, according to customer requirements, to enable companies to create an IPD environment.

2.3.1 Reasons for Implementing PDM

The most important reasons for our implementing PDM are to:

- monitor/control applications that generate data
- find the right information
- make project work more effective
- increase access to and distribution of information
- gain an overview of the relationships between all of a product's parts and components.
- stimulate our teams to work even more effectively than they would with IPTs alone.

We also believe that we need such tools to succeed and survive in the future.

2.3.2 PDM System Solution Vision

The system will tie together all the elements needed for development and production of a product (refer to Figure 5).

The PDM system ties together the WBS and product structures with the corresponding results of the tasks, e.g., SW code, 3D models, mechanical analysis and documents, and connects the Part/SW with corresponding models (3D, analysis, behaviour), process, documents, etc. In our old CM system, typically, only formal customer-specified/customer-required documents were stored, not the files or much of the other information generated in the projects. The PDM system also makes it very easy to include the informal and internal information. This sort of information is vital for knowing the reasons behind decisions, alternatives, trade-offs and discussions.

The PDM system will be coupled together with the other computer systems at different levels of integration. The M-CAD and E-CAD systems will be tightly integrated , e.g., the product structure (very detailed level) will be automatically generated in the PDM system on the basis of the information generated in the CAD systems (minimisation of non-value-added activities and increasing of quality).

In teamwork, access to the right information, in any format, is vital when needed. This requirement is supported by the PDM systems. All information is accessible for team members, when they need it, on whatever hardware platform they use (Mac, PC, etc.) and whether they have the native application or not.

With this system, all required information is guided through the project. The status of all information is recorded and connected to the respective working processes. The PDM system enables reuse of information, across project steams, since the information is easily accessible and sorted in structured ways.

Further, the PDM system also includes a "library" of approved standard mechanical, electronic and system components.

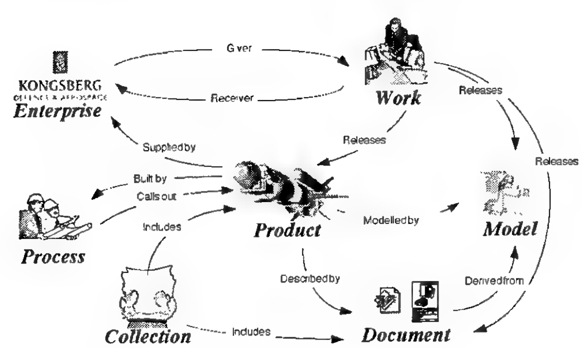

Figure 5 Integration and relation between the elements needed for product development

Figure 6 illustrates the total system integration for the life cycle of the product.

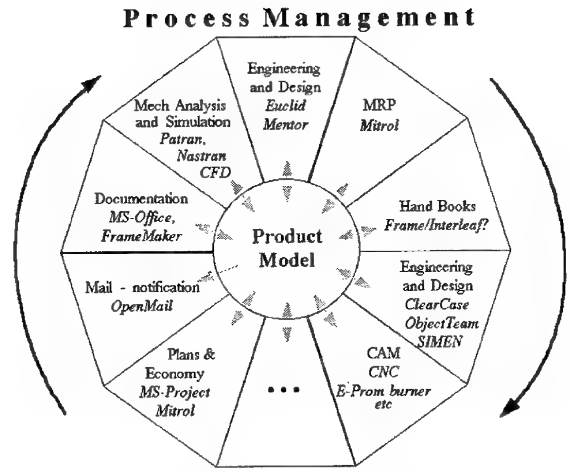

Figure 6 Total System Integration for the life cycle of the Product

The MRP and shop-floor control systems will be fed with data from the PDM system. This data will be Bill of Materials, effectivity information, references to production documentation (including videos), etc.

2.4 IS/IT Strategy

It became evident that we needed some guidelines when selecting systems to avoid multiple local systems performing identical tasks, e.g., cost managers looking only at their local costs and not the total cost for the project and the company.

We did not have a clearly written IT strategy when the project started. Afterward, it was evident that we needed an overall IT strategy on which to base our work. We then hired a consulting firm (ISI) to help us establish an IT strategy and support the implementation of the IPF project.

ISI confirmed our findings on business processes. Hence, we combined the processes and the IT tools more tightly, and started to document and structure the processes as shown in Paragraph 2.1.2. We also realised that the way we organised IT (in a computing centre) was not sufficient—we had to distinguish between the systems (IS) and the supporting tools/techniques/ department (IT). As a result of our work with IT strategy, we reorganised our IS/IT functions for more effective use of our computer tools.

2.5 Overall interaction of the sub-projects

The IPF project had a time frame of approximately three years and was run in parallel with the ramp-up phase for the first customer of the IPF project, NSM. This short time frame resulted in a need for performing several sub-projects in parallel which has been a complicated and difficult task, but has made the interaction and mutual influence of the sub-projects easier and more efficient.

3. EXAMPLES OF WHAT WE HAVE DONE, WITH RESULTS

We were able to verify the concepts mentioned in Paragraph 2 through a number of "live" tasks in the NSM project. One of these is described following.

3.1 The development of a generic section of a missile composite body

This Paragraph is based on ref. [Brei97].

Due to the complexity of advanced composite structures, and the variety of engineering disciplines involved in their development, a strong CE approach is vital to the manufacturing product. In order to develop optimised composite structures, it is therefore necessary to use IPTs.

The IPTs with representatives from materials, structures, manufacturing, tooling, quality, purchasing, and logistics, are very capable of efficiently designing, developing, producing and supporting composite structures. Each discipline is fully informed about status for all of the other areas involved. Optimisation in this context refers to right performance, weight and cost at a minimum of schedule.

The development of composite products illustrates the effective methods of reaching goals in-house by means of deliberately progressing with IPD from concepts to final hardware.

3.1.1 Part Description, Goal and Progress

A generic section of a missile body has been developed from scratch. The final product consists of two load-carrying composite body halves bonded together by means of mechanical fasteners. The composite parts have been riveted to metallic profiles and strong rings

The aim of the project was partly to minimise cost and time by using CE instead of conventional development methods. This approach would give us the potential for assessment of forthcoming full-scale development projects. The team members were all trained in advance for using modern data tools.

It was further decided to employ composite tooling for the composite parts. On the basis of previous experience, this tooling would give the most time- and cost-effective solution for generating hardware to prescribed quality. Preparations for moulding a composite tool included a master model.

The team used our 3D CAD/CAM system very efficiently. Simultaneously, through common access to the EUCLID database, personnel from mechanical production checked the surface modelling of the master model. This control of the tool designers work ensured that no extra rework was required when the data model was used in production. There was correct modelling, radii and use of tolerances, ensuring smooth transition of information to the CNC machine. Simultaneously, with tool design, the CNC programmer was able to start preparation of the milling, drilling and sanding operations on the basis of current status of the EUCLID model.

By personnel from the composite workshop, assembly shop, metal workshop and structures, the parts were optimised through team work with regard to strength/ stiffness and produceability.

The section of the missile body was successfully assembled to provide a very useful process evaluation and test object.

3.1.2 Concurrent Engineering vs. Conventional Engineering

What overall experience characterises the difference between the old and the new methods of composite engineering development?

- First, with conventional engineering, large proportions of information are based on evaluation of paper printouts. Drawings, processes and documents are copied, registered at CM, and distributed for evaluation. However, this method is both time consuming and costly. And if the documentation is registered, the procedures for all red-marked changes sometimes can be very comprehensive.

  Further, it is not uncommon that the producer of the information prepares his own work in too great of detail before considering communication with relevant project personnel from other disciplines. This lack of teamwork reduces the possibility of all project collaborators identifying the required engineering changes before too much rework is mandatory.
- CE, on the other hand, is based on the extensive use of electronic communication within the team. In addition, everyone had access to a common database such as the EUCLID system. This ensures a quick and sometimes simultaneous communication and problem solving discussion where and when required. Updates on drawings and process documentation are performed with time and cost effectiveness.

  Verbal communication, however, is still the most important source of information. This can be practised through established cross-organisational teams of required personnel who act together with common goals. This communication will ensure that no unforeseen, delaying and costly problems occur in critical phases of the project. At the same time, preparations for the next step of the development cycle can start well in advance of the actual task coming up. The IPTs will work together from early concept phase to final produced hardware.

However, even relatively small projects, such the generic missile body, for example, have shown that several traps must be avoided for success. This is discussed below.

3.1.3 Lessons Learned

- A successful project based on extensive use of IPTs largely depends on the capability of each team member for patience and co-operation. Changing well-established work routines, which can sometimes be troublesome, requires open minds and positive attitudes. A reorganisation of the team or a modification in project leadership may be required.
- Communication and frank acceptance of new ideas and changes are important for the evaluation of all possible solutions. Often production personnel are best qualified to comment on the optimum way of forming a product. In such situations, it is important that engineers and designers are willing to listen, discuss and accept alternative solutions.
- Feedback between the various project disciplines on cost, quality and progress is vital to success. In an on-going project, interdisciplinary communication is the best means of improving the next application of a solution. Additionally, a new project will gain useful information about lessons learned from the feedback.
- Cost- and time-effective use of modern IT systems, like design, analyses and production systems, is only possible if the users are well-trained in advance of the project. These data tools have so many "advanced" methods of use for optimum output, that their effectiveness will only be realised by experienced personnel.
- Even though progress in the development of electronic modelling may be successful in the project, it must be remembered that production of hardware for a prototype series depends on availability of production tools. That is, even for a smaller series production, for example, of prototypes, the process depends on detailed planning assuring that current customer-related production does not occupy all available machinery.

3.1.4 Time and Cost Savings

For the above-discussed one-time manufacturing of composite products, the following cost and time savings have been realised for CE at KDA, compared with more conventional engineering:

Table 3 Cost and Time Savings for Composite Products with CE

	Lead Time	Cost:
Design, analysis and production of hardware through IPTs	3-4 times faster	25-50% lower
Design and Production of wind tunnel models using LMT	4-6 times faster	50% lower
Design and production of LMT tools (rapid Prototyping):	4-6 times faster	50-75% lower
Unfolded geometry for prepreg templates plotted in scale 1:1	3 times faster	25-50% lower
Total development and production loop of part, up to assembly	3 times faster	

These figures are restricted to the development and production of one-time parts under ideal conditions. For the development of complex full-scale details and the series production of such parts, the situation to a certain extent will probably be different.

4. DISCUSSION AND CONCLUSION

Approximately 150 of our employees have been involved in the IPF project since its start in 1995, and most of them have been end-users. The work has been done in tight co-operation with our internal Organisational Development staff, the Norwegian University of Science & Technology, SINTEF, Work Research Institute, ISI and the IS system vendors. External inputs have been vital as it has been very difficult to diagnose our own organisation and working patterns.

It has been vital for us to adjust the way we work according to the abilities of the IS systems. The Industry's best practise, as implemented in Sherpa IPD, has been introduced with only minor adjustments. Improvements and modifications of the processes simultaneously with the implementation of new IS systems have been difficult, but the efforts give very good results nonetheless. Involvement of end-users has also simplified buy-in in the user-community. The majority of the people who have been involved have been very pleased with the results, despite the difficulty in changing individual behaviour.

The involvement of end-users has also been time-consuming and expensive up front, but the ROI on this investment is very short when the methods of the IPF project are used on a daily basis.

A lot of the concepts have been defined through theoretical discussions, an effort which has proved to be difficult. When we were able to demonstrate the theories through real cases, processes went much smoother.

A two-day dialogue conference (ref. [Påls97]) for all NSM project members, with concrete discussions on how to best employ the CE project, and to reaffirm the CE project and work within NSM, was run medio March 1996. It consisted of 91 participants from KDA. The main purpose of the conference was to sharpen the abilities of NSM personnel to create and operate the kind of working methods demanded by CE. In accordance with the WRI basic concept of the relationship between development (or improvement) tasks and operational tasks, the dialogue conference was organised in a way that would give each participant a maximum of opportunities to contribute concretely to the discussions on how CE strategy should be practised

Whether or not it was familiar, this logic worked for KDA. The majority of the participants considered the dialogue conference an important forum for a better understanding of the need for applying CE working methods in NSM.

We have had a lot of discussions about the responsibilities and tasks for the functional line organisation versus the project organisation. In our earlier practise, our functional line managers approved the solutions of technical concepts. This work method is impossible in an effective CE environment with the speed and budgets which are available. The main responsibilities of the functional line organisation in the future shall be to have:

1. resources with correct competence
2. tools which are used in optimal ways
3. oversight of the different processes.

That is to say, the organisations will achieve good technical solutions through these three responsibilities and not "inspection" of the quality/solutions afterwards.

The demonstration which has been performed has verified the concepts of the IPF project and made the adoption of CE and the computer tools easier in the organisation.

5. ACKNOWLEDGEMENTS

The IPF project is partly funded by the Norwegian Research Council, and we are grateful for this support and the interest they have shown to our work. The work performed by representatives from the Norwegian University of Science & Technology, SINTEF and Work Research Institute, has been of great value and we are thankful for their involvement. Our discussions on CE, PDM, etc., with numerous other companies have been a valuable way of learning; a corresponding attitude will be followed by KDA.

I am grateful for the support and confidence the project has received from the upper management of KDA, especially CEO T. Gerhardsen and CFO K. Nordstrand, and the rest of the steering committee.

Finally, the project work could not have been achieved without the 150 people who have participated with great enthusiasm and spirit.

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CMT - AN INNOVATIVE SYSTEM FOR PROJECT RISK MANAGEMENT

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ABSTRACT

A risk management system called Criticality Management Tools (CMT) /1/ is introduced. This system (procedures and software tools) supports a preventive and proactive approach, which enables early identification of hazards and risk affecting the project objectives. The hazards may originate from a broad range of disciplines, such as economy, politics, technology, environment, etc. An information management module contains the resources needed to perform risk monitoring and controls experience data collected from surveys and pilot projects. These data will be continuously updated with experience gained through the use of CMT in ordinary projects.

1. Introduction

Defence industries occasionally experience projects which are characterised by large cost overruns, substantial delays and major quality or performance deficiencies. With the last years defence-budget cutbacks in the various NATO countries, the need for a cost-effective management of projects has become immense. Common to most of these projects are their substantial complexity, thus making project management a difficult task. It seems that there are inherent and sometimes inevitable risks and uncertainties associated with complex projects. The ability to manage and control risk thus becomes an integral part in obtaining project success.

Negative deviations from the project objectives are often claimed to be the result of unforeseeable and uncontrollable risk causes (called hazards) such as technological problems, contract disputes, marked changes, political interference, human or organizational problems and/or mismanagement. However, in this paper it is claimed that most hazards are in fact predictable and controllable, and that project failures are largely the result of lack of early attention by project managers due to the information and work overload occurring in complex projects.

On these grounds a project risk management system called CMT (Criticality Management Tools) is being developed. The CMT project is a cooperative R&D project between a large supplier; Aerospatiale Missiles (ASM), a large buyer; The Norwegian Defense (NDA), and a major risk assessment and quality assurance organization; Det Norske Veritas (DNV). The CMT project was initiated in late 1993, and the

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development phase is planned to run for a 4 year period with a total investment of 25 MNOK.

The main objective of the CMT project is to develop a systematic approach to identify, assess and control risks in projects, programs, and portfolios. The CMT system (software tools and procedures) supports a preventive and proactive approach, which enables early identification of hazards and includes risk scenarios from a broad range of areas. This will lead to a cost-effective risk handling, as most hazards (and certainly the project objectives) are difficult and expensive to change once the project has been defined, the contract signed and the project activities started. Although CMT is primarily a tool to control risks with a downside potential, it is also well suited for handling opportunities, i.e., "upside risks". Being an aid for cost-effective decision making in this regard, the application of the CMT system may lead to project savings of at least 2-5%.

Main components of a risk are its hazards and their associated consequences which are defined as a deviation from the project objectives. In principle, all types of hazards and consequences can be handled by CMT. Hazards may originate from domains like politics, economy, technology, communications, project management, human relations, and others. These hazards may in turn have consequences to the project objectives, such as cost, schedule, product quality, safety, goodwill, environment, etc.

To facilitate the CMT process a computer tool called EasyRisk is being developed. This program may be operated in two modes - standard and advanced mode. The standard mode is a "CMT-light" version and is very easy to use, while the advanced mode offers the flexibility of complex scenario modeling using influence diagrams and Monte Carlo simulation technique.

So far, the CMT system has been implemented in 6 pilot projects. These projects have provided important feedback to the development team, including experience data which are used to build an experience database consisting of generic hazards and risk scenarios. The pilot projects also serve as useful validation of the CMT procedures themselves. Thus far it seems fair to say that putting focus on risks has had a positive effect on the projects. The extra awareness of critical risks may precisely be the main prerequisite to avoid them.

2. Risk Management Philosophy

A project is always an undertaking involving risks. Whereas management of such risks have been left to the project manager in the past, it is now becoming more and more usual that larger and complex projects encompass a separate risk management function /2/. The main objective of such a project risk management (PRM) function is to identify and structure information to (i) ensure that all the risks are managed, and (ii) ensure that all the actors are aware of the interfaces towards their own work that involves risk. The risk management function may thus be viewed as a quality assurance function of information flow in projects, to ensure proactive management of such information, and finally improve success-rates of projects. The following scenario-based logic can be used to explain some central concepts:

A project is executed in order to achieve certain
project objectives which are defined in terms of schedule,

budget, performance of system development, etc. A deviation from these objectives is defined as a consequence. A risk scenario starts with

project hazards which may lead to

consequences measured as outcome severity and probability of occurrence. This measure is called risk and is used to categorize the effect of each hazard into

risk classes in order to decide whether to

ignore, monitor or mitigate the risk(s)

The above (chain of) events and conditions are the 'building blocks' of project risk scenarios.

2.1 Why Risk Management?

While negative deviations from the project objectives in the past were often attributed to uncontrollable factors outside the project and thus to some extend neglected, the tendency nowadays is rather to put focus on these risk causes. Early identification and awareness of the risks affecting the project will in general enable the project to respond and act in a way that leads to cost-effective risk handling. This will in turn also lead to better fulfillment of the project objectives (budget, schedule, quality, etc.)

2.2 Dealing with Uncertainties

It is a well known fact that humans have a strong tendency to engage in tasks which are familiar and to underestimate and avoid uncertain issues. Why then put focus on uncertainties? First, merely ignoring the uncertainties will not make them go away. On the contrary, you thereby increase the likelihood that they will effect your project in a negative way. Second, the uncertainty can sometimes provide useful information that can be crucial for decision making. To exemplify this in a straightforward manner, assume that you were to decide between two alternatives, where the estimated cost of alternative A is $1000 and alternative B is $1100. If the two alternatives can be considered to be equally good in terms of the delivered item, you would, with no further information, most likely select the alternative with the lowest cost, i.e. alternative A. However, let us review this decision taking the uncertainties into account. If the more expensive alternative was a COTS project, while the other included some development, the uncertainties associated with the cost estimates would be very different. For the sake of argument let us assume that the uncertainties in the costs were described by probability functions, as shown in Figure 1. The more expensive COTS alternative can be seen as a low-risk project as the cost estimate is rather certain. For the development alternative, on the other hand, the standard deviation in the cost estimate is significantly larger. In effect, the development project is quite likely to give real project costs above the ones of the COTS project. With this additional information at hand, the decision maker is more likely to choose the COTS alternative, despite its larger estimated cost.

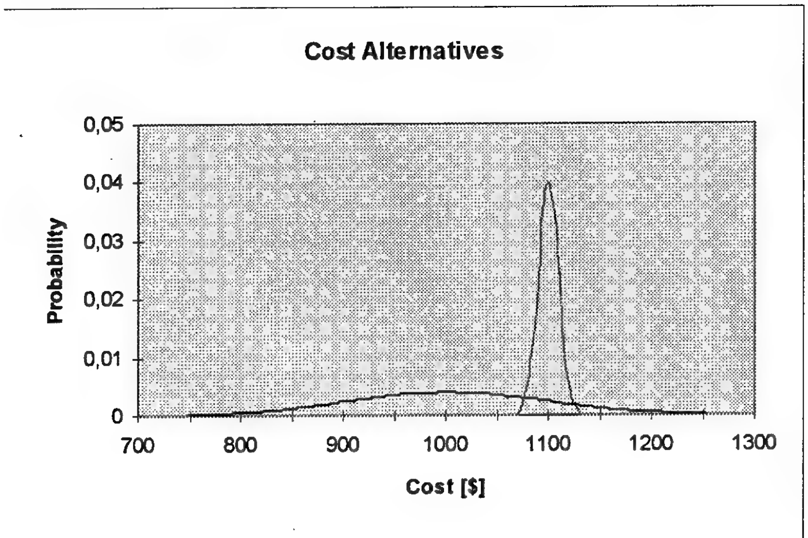

Figure 1: Cost-estimates including uncertainties for two project alternatives.

2.3 The Risk management Process

The following general principles should guide the development of any modern risk management (RM) process /3/:

- RM should be a systematic process, consisting of a method and a sequence of steps directly supported by a software program.
- RM should be flexible, because the thoroughness invested in information management (especially data collection) should be adjusted to the project at hand.
- RM should be intuitive, i.e. the user interface and way of operation should be simple and easy to understand, and reflect the situation of the end users.
- RM should contain guidance to the user on what to do, when and how.
- RM should support the decision making, by letting the consequences of different decision alternatives become clearer.

The CMT RM process has been designed to meet these objectives.

3. Criticality Management Tools - CMT

In CMT focus is put on the risk and their causes, i.e. hazards. By identifying and controlling the risk causes, one supports a preventive and proactive approach, which enables early identification of hazards and project risks. This in turn will lead to cost-effective risk handling, reducing the need for expensive "after-the-fact" mitigations.

3.1 The CMT process

The CMT risk management process consists of the following main steps:

- Initiation: Project objectives are identified. In this step risk acceptance criteria are also defined and a Risk Management Plan is prepared. The preparation of this plan implies that the generic CMT approach is tailored to

the needs and conditions of the project at hand.

- Hazard Analysis: Relevant hazards (risk causes) are identified, using check-lists, generic scenarios, generic projects, experience from other relevant projects, brainstorming sessions, etc. In principle, all types of hazards and consequences can be handled by CMT. The hazards may originate from domains like politics, economy, technology, etc. These hazards may in turn have consequences to the project objectives, such as cost, schedule, product quality, safety, goodwill, etc.

- Risk Assessment: Data is collected or estimated for the hazard probabilities and consequences, and for other relevant variables in the risk scenario. (A consequence means a deviation from the project objective.) The hazards are then classified according to the risk they represent on the various project objectives. Typically, three risk classes are used. Negligible risks (against which no particular action is required), Significant risks (which are acceptable on the condition that they are constantly monitored and re-assessed), and Critical risks (which are unacceptable risks, against which actions must be deployed).

- Action Analysis: Potential actions are identified, and their risk-reducing effects are evaluated. The actions are then ranked according to their cost-benefit value.

- Action Deployment: A given action is selected and initiated (deployed).

- Post-Implementation Evaluation: The relevant risks are re-evaluated after the action(s) have been implemented and the effects have materialised.

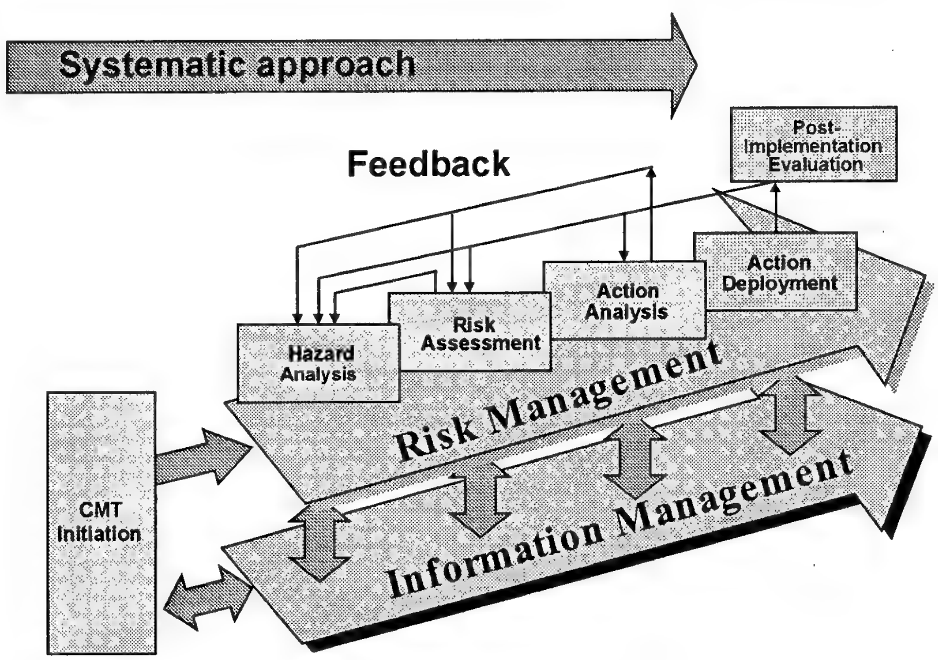

Figure 2: The CMT process overview

This process is iterative, thus capturing the dynamics of the risk management process: Periodically or whenever needed, one must redo the necessary steps in the process. The risk analysis steps are illustrated in Figure 2.

The CMT process can be performed in two different modes - standard and advanced. The standard mode is a "CMT-light" version, which is easy to use and provides the analyst with immediate, but simplified results. The advanced mode offers the flexibility of complex scenario modeling using influence diagrams and a Monte Carlo simulation technique.

In CMT, project risk is either defined as the expected deviation from project objectives, or related to the uncertainty associated with the objectives outcome. The first definition is used in the standard mode, while the advanced mode takes the full uncertainty as well as the interdependency between risk causes (hazards) into account. The standard mode disregards uncertainty, as it - for each hazard - only considers the typical value of the of the severity of the deviation (consequence) and the typical or mean probability of occurrence for that deviation.

The standard mode analysis will typically be the starting point for a more advanced analysis. Due to its simplicity it allows non-experts with little background in statistics to participate in the risk analysis. This is crucial for a successful implementation of the CMT process in the organization, allowing the end-users to build up their competence in a gradual manner.

3.2 Computational Tool - EasyRisk

A computer tool called EasyRisk is being developed to facilitate the CMT process and its documentation. It supports the two modes of CMT - standard and advanced.

In both modes of operation the hazards (selected from a built in list, or new) have to be evaluated with respect to probability of occurrence and severity of final consequence. This can be done on a user selectable (3, 6 or any-point) scale, or with advanced probability functions. When hazards have been identified and assessed, they are classified according to the risk they represent to the various project objectives. Typically, three risk classes are used: Negligible risks (against which no particular action is required), Significant risks (which are acceptable on the condition that they are constantly monitored and re-assessed), and Critical risks (which are unacceptable risks, against which actions must be deployed).

3.3 Calculational Techniques

In the standard mode of CMT each hazard is treated independently and evaluated without regard for uncertainty. This simplification, although sometimes appropriate, usually conceals useful information. In the advanced mode of CMT on the other hand, one uses scenario modeling to reflect the interdependencies between the various hazards and events. The variables in the scenario can also be assigned the appropriate probability function to reflect the associated uncertainty in its mean value. This approach provides the decision-maker with more comprehensive risk data, allowing e.g. the following:

- A multiobjective formulation: Several objectives can be taken into account, using the theory of utility theory./4,5/ This allows the decision-maker to perform trade-off analyses between diverse and possibly conflicting objectives: It may not be beneficial to hit bulls-eye on one objective if that means you have to deviate strongly on another objective.. The multiobjective formulation is designed in a way allowing CMT to also cover portfolio management. For this purpose the various projects themselves represent the different "objectives", and the portfolio management then allows for trade-offs between different projects and total risk calculations on the portfolio level.

- Sensitivity analyses: The scenario is analyzed in order to locate its most sensitive and most important elements. This information is in turn used to identify what type of actions will be most cost-effective, and where in the project-scenario they should be implemented.

- Upside-downside risk considerations: In the advanced mode the simulation provides probability functions describing all the possible outcomes of the objectives, thus covering both the upside and downside potential.

3.4 Information and Experience Management

The importance of information and experience management in complex projects cannot be overestimated. Most project failures are largely the result of lack of early attention by project managers due to the information and work overload occurring in complex projects. To facilitate and structured the handling of such information, and thus simplify this process, the CMT system is equipped with two important tools:

- The Risk Manual: A folder supporting the documentation in the various steps of the CMT process. This folder follows the project through its life-cycle, documenting the risk status at any time. Using Easyrisk, these documents can be printed out directly and put in the Risk Manual. This way the risk management information is utilized, structured and documented.

- Project Risk Experience Database: A database of different projects with typical hazards, objectives, actions and their assessments. Various "lesson-learnt" evaluations are also included in these database. EasyRisk is delivered with a database consisting of generic projects, generic scenarios, generic hazards, and generic actions. Typically each user organization will adapt this database to their own organization, reflecting the typical hazards and risks occurring in their projects.

4. Experience from use of CMT in pilot projects

The CMT system has so far been implemented in 6 pilot projects, where the cost of implementation has been split between the CMT development project and the actual project. Demanding that the projects themselves covered some of the costs was done deliberately to secure their genuine participation in the pilots.

The pilot projects serve several purposes:

- Provide feedback to the CMT development team regarding functionality and user friendliness of EasyRisk.

- Validation of the CMT procedures themselves
- Provide data for the CMT Project Risk Experience Database
- Prepare for a full implementation of the CMT system in the organization.

A true value of the project saving by the use of CMT in the pilot projects is hard to predict, but estimates may indicate savings of at least 2-5%. When CMT is firmly established in these projects and the full strength of the computer tool EasyRisk is exploited, this number is likely to increase.

The reactions so far from the members of the pilot projects have also been positive. When CMT was initiated in these projects, focus was first put on reducing (downside) risks. The interest and engagement from the project members was surprisingly high, indicating that they were not unfamiliar with the concept of hazards and risks. But so far there had been no systematic way to treat or document these "potential problems". CMT now provided a systematic system for them.

As CMT became familiar to the project participants they also began to consider "upside risks", i.e. opportunities. During CMT sessions the members now outdid each other in brainstorming possible opportunities for the project. No longer did they worry about exceeding the budget; they wanted the project to finish below budget!

The pilot projects have provided useful feedback to the development team, allowing them to refine both the process, procedures and the computing tool EasyRisk. But maybe most importantly they have told us that there is both a need, demand and desire for Risk Management.

5. Summary

A risk management system called CMT is introduced. The CMT system consists of both procedures and software tools. CMT provides a systematic approach to identify, assess and control risks in projects, programs, and portfolios. The focus is put on the risk causes - the hazards - as CMT supports a proactive and preventive approach. The hazards may originate from a broad range of disciplines, such as economy, politics, technology, environment, unrealistic requirements, etc.

To support the CMT process a software tool called EasyRisk is being developed. The computer program guides the user through the various steps of the process and facilitates the information and experience management. On a day-to-day basis the program is used to keep the Risk Manual updated. The Risk Manual documents the risks that may affect the project, and follows the project through its life-cycle, documenting the risk status over time. In addition EasyRisk maintains the experience database.

The experience from implementing CMT in various pilot projects has been encouraging. Putting focus on risks has had a positive effect on these projects. The extra awareness of critical risks may precisely be the main prerequisite to avoid them.

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PAST AND FUTURE PROGRAMMES:

A VIEW ON COST MANAGEMENT EVOLUTION AND CHALLENGES

by

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Introduction

The challenge of meeting the requirements for an effective air combat capability in the future, constrained by ever more demanding budgetary limitations, must be faced in the broadest possible terms to identify the affordable solutions.

Cost analysis of a weapon system must consider the entire life cycle of the system, from initial concept and realization of the first series through the variants which scenario requirements and technological evolution impose on the system to maintain an operational capacity which meets the demands of intended use.

The cost of a programme in its entirety, i.e. the Life Cycle Cost (LCC), is essentially determined by the physical parameters of the system produced and the process by which it is realized and managed: it is of course true to say that developments both in the recent past and currently in evolution have led to techniques and procedures which aim to reduce such effects to a minimum. However, in general terms, the level of cost is determined by factors of a general nature which reflect the system requirements and the contractual framework within which it is developed, acquired and managed during its lifetime.

Experience gained in various programmes operative during these years in which cost management techniques have been identified and to a certain extent put into practise, suggests the need to cross-analyse such elements of cost control: in a similar way to the constraints of requirements and contractual typologies they can condition the effectiveness of the techniques and procedures of cost management.

The Structure of Weapon System Life Cycle Cost

The problem which the Armed Forces and their governments must face up to is that of procuring an affordable Weapon System in a situation of ever greater financial limitations for armament updating, as reasonably enough takes place in periods in which world-wide conflicts are considered to be of low probability; there may be acute localised conflicts, however, and it is these that justify the need for adequate weapons systems, however their limited extent reduces the allocation of finances within the national economic balance.

The decision to develop the necessary weapons systems requires an accurate economic analysis which covers all aspects of their life and their utilization; attention must therefore be dedicated to the most cost-effective solutions during the acquisition process and the management of all the phases of the weapon system's life.

The dominant phases of LCC are those of acquisition, that is the development and production and of the product support to ensure the availability and maintainability of the system; however, the increasing longevity of the product and the diversity of present day technological and operational scenarios are increasingly playing a larger role within life cycle cost analyses due to costs of modernization and development of new versions.

The dominant concept of LCC optimization is that of analysing the implications of design choices on

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each element across its life span during the product conceptual phase, and adopting within the design requirements those elements which can reduce the costs of successive phases, to make available during development all the elements which make the development of successive phases affordable.

In this light, the Design to Cost approaches were initially concentrated on design to reduce the costs of production of the systems and their in-service costs; during the 1980's the concepts of integrated logistics support were advanced, aiming at the optimization of operational support of the system, beginning with design solutions that responded to requirements for reliability, maintainability and testability with the objectives of ensuring the design and accomplishment of a logistic support system at a foreseeable cost, optimised for the programme, and able to be used in various projects. And with the aim of long-term use, concepts of modularity in the architectural configuration of the airframe, open architecture and dual standardization (civil and military) were introduced, as elements which inserted in the optimization loops of a project tend to reduce the costs of modification improvements and successive important upgradings.

During the 1990s, studies regarding the reduction of LCC have been concentrated on the optimization of the processes of development and production: techniques such as concurrent engineering, integrated product development, virtual design environment and lean production aim to reduce the intrinsic costs of the process, without loss of quality.

The success of these various techniques for the reduction of costs across the entire life of the product is of course conditioned by the peculiarity of the single project itself; experience gained in those cooperative European projects in which we have participated can be used as a guide in the analysis of the potential of these techniques and conditions of cost management against which we can measure the projects of the past, and possible future programmes.

Elements which condition the cost of a Weapon System

The previously mentioned LCC analyses consider determinant elements which, when opportunely applied, can optimise the global cost of the Weapon System. However, the class of cost is determined by other elements of a more general nature which thus must be considered in the light of management of the cost necessary to satisfy the requirements.

Apart from the technical parameters of cost referencing, such as aircraft mass, number of engines, avionics volume, flight envelope etc., it is the complexity of the original customer requirement that conditions the level of cost of a programme while it is the contractual conditions that allow the evolutionary control of the process in terms of economic risk.

In the requirements, there are two fundamental conditioners: the level of performance requested for the Weapon System and the number of operational roles specified; at the same time, two other aspects are significant for the class of cost - the logistic support system and the rules governing the qualification/certification of the project.

The requirement is the most critical element for the programme and is the most difficult to identify, being the result of a strategic vision of the operative and technological scenario of the future, where against those aspects of political evolution and technological development available we must weigh up the possibilities of the potentially antagonistic environment. And the longer the period of forecast is, the more we must make reference to sophisticated performance and therefore ever more complex technological development.

Similarly, the request for the basic system to cover roles significantly different from each other has a multiplying effect on the complexity of the project, thus again requiring solutions involving advanced and sophisticated technology and greater architectural integration.

In the definition of the cost, the implications within the process of a simultaneous design development and technological development must be considered with great attention as their relative interrelationships lead to repeated processes and cycles of specification, manufacture and tests. The intrinsic characteristics of a technologic development additionally bring uncertainties and consequent caution which have a significant effect on costs.

The operational costs of the system represent one of the major components of the total cost, and therefore

the specification of the logistic support system is of major relevance. The possibility of using a single logistic system in support of a multirole system or by different weapon systems represents a significant economy which is achievable with an appropriate specification in the requirement.

In addition, the reference Standards (MIL, Stanag etc) have their effect on costs. The definition of the Standards is based essentially on a range of conditions taken from the past experience, which tend to guarantee the reliability and safety of the project solutions. Strict adherence to these Standards does not in fact facilitate the optimization of the project, nor does it permit for example the use of civil components which frequently have very competitive costs.

Another element which has an indirect effect on the cost of a programme is linked to the contractual conditions in which a programme is inserted, and there are two significant aspects which experience has shown to be cost drivers: a multinational contract and the specific typology of the contracts themselves.

In Europe, the national strategic requirement have imposed, due to high development costs, collaboration in the development of important programmes between the various nations and between companies in the different countries with a variety of industrial realities.

The homogeneity of operational and procedural requirements between the various cooperating countries in a programmes is undoubtedly a determining factor on the complexity of the requirement. The progressive political integration between the European nations is fundamental for the elimination of this complicating element.

Equally relevant but more complex to achieve, is the homogeneity of financial planning of the various nations. That would enable a reasonable time flow of the acquisition process optimised to control costs.

The collaboration between industrial situations originally widely differing has undoubtedly added to the costs of multinational programmes: a certain burden has been the costs of harmonizing technologic know-how and design procedures. However, one this problem has been overcome, the management of programmes in multinational partnership is an opportunity to grasp in order to make use of the best characteristics of the diverse industrial and cultural realities which exist.

The cost of programmes which were the first to take this approach, such as Tornado, was relatively high: at the same time they allowed the development of a wider and more uniform industrial environment which today could be, if employed rationally, an opportunity to improve the competitivity between the new intercontinental industrial conglomerations both for the potentiality of a rapid technical aggregation of the available resources and for the contribution of the best characteristics of the various cultures and industrial realities.

Even if however, it were possible to assert that multinational contracts would not conceptually have significant impact on the cost of the programmes themselves, the typology of the contract indirectly but assuredly conditions the economic aspect.

The "cost-plus" type of contact which characterised the Tornado programme during the basic development soon showed themselves to be extremely difficult for financial planning, giving origin to significant creep in the costs forecast for the technological complexity of the requirement. The direct involvement of the Customer in the technological development of the programme reduced the industrial risk.

This was a notable example of how national egoism can be overcome, by means of the highest collaborative spirit between the participating companies. And it was an important contribution towards the creation of a condition of world-wide competitivity of the European aerospace industry.

Firm/fixed price contracts, such as that for the EF2000 programme were launched to have a greater control of costs of the programme. This type of contract, where the partners of the consortium are clearly faced with predefined economic objectives, has certainly stimulated much greater attention to development process improvement, but has tended to create a more conflictual relationship between the participating companies, causing delays which can be economically dangerous, for the high risk involved. It is a sobering thought to remember that in many other occasions, programmes contractually imposed at a fixed/never exceed price have experienced big troubles!

Aspects which have a negative influence on contractual implications become undoubtedly more dangerous in proportion to the technological complexity and/or length of duration, i.e. when the uncertainties of the programme are greatest. It may be a banal observation, but it nonetheless suggests that contractual differentiation during the various phases of a programme, coherently with the evolution of technical and scenario certainties may be an instrument of cost management for acquisition and during the full life of a weapon system.

PAST AND FUTURE ALENIA PROGRAMMES

The TORNADO Programme

The Tri-National (IT/GE/UK) TORNADO programme was conceived in 1969 based on requirement MRCA 75 (Multi-Role Combat Aircraft with ISD (In-Service Date) forecast in 1975). The principal characteristic of the requirement was related to the capacity of high speed penetration at low level (tree top) in strike role and A/A combat within the entire transonic/supersonic flight envelope in Air Defence role. Satisfaction of the requirement forced necessity for advanced technologic solutions such as:

- variable geometry
- new generation engines
- advanced high lift devices
- automatic Terrain Following capability.

The required technological complexity caused the modification to the original time estimate for the programmes with an acquisition period that changed from 6 to 12 years and an increase in relative cost more that twice compared to the original estimates.

The multinational customer (NAMMA), aware of the technical challenge undertaken, was directly involved during the development thus reducing the industrial risk with the stipulation of a cost-plus type contract, which guaranteed European Industry the production of a system of the highest technical characteristics, placing it at the summit of weapon systems of similar class.

The EF2000 Programme

The EF2000 programme was conceived during the 1980s within an operational scenario characterized by the counter-position of the NATO treaty countries and the Warsaw Pact as the European answer (EFA = European Fighter Aircraft) to the threat of a possible attack from the East (Soviet bloc).

The programme is conducted by the "Eurofighter" company, constituted in partnership by the principal companies of the participating nations; it is managed on the behalf of the National Customers by the Agency NEFMA/NETMA.

The technical characteristics thus foresaw a high manoeuvrability capacity in all flight regimes (sub/trans/supersonic) through an intrinsically unstable delta-canard configuration controlled by a full digital fly-by-wire control system and supported by an exceptionally high thrust to weight ratio, advanced concept engine in a platform mainly built from composite materials and innovative alloys to minimize the weight.

The difficult operational scenario behind the project requirements necessitated the creation of a weapon system with an intrinsic "first look - first kill" capability, obtained through a complete situation awareness by means of the integration and fusion of data from active and passive sensors of the latest generation. The lethality of the system is guaranteed by a notable capacity for carriage and launch of advanced Air-to-Air missiles managed by a sophisticated attack and control armament system. These requirements have imposed a strong technological plan in addition to the EAP Demonstrator programme.

Currently the programme is in full development phase, with seven prototypes flying at the various European flight test centres, waiting for the start of the production phase. System development is covered by a general contract agreed with Eurofighter of the "firm fixed cost" type and converted in national contract with leader companies of the participating countries covering those aspect of System Design Responsibility (SDR) defined at Eurofighter level.

Future Programmes

In perspective, the geopolitical situation can still be characterized by a reduction in threat density, notwithstanding a generalized diffusion of areas of conflict: this tends to the identification of requirements for future weapon systems which will call for operative performance of a level not significantly greater than those current but with a reduced number of systems with respect to the past.

Under these conditions, the scenario which emerges might contemplate both the use of a limited number of complex multirole systems, typically aimed at the replacement of the current systems in use (TORNADO, Mirage 2000, etc.) and, long term, of the EF2000 and Rafale, as well as the deployment of simpler and hence less costly systems with a specific tactical role.

These last raise the possibility of developing specialized systems of high automation and autonomy, where flight, navigation, command, identification and acquisition of targets / objectives can be made without pilot assistance, uninhabited systems, which presumably only in some critical moments (fire, no-fire) will require human decision.

The absence of human element aboard will considerable simplify the weapon system and the concurrent tendency to singularity of role will reduce the necessity for specific technological development.

Effectiveness of cost management techniques

The techniques and the procedures aimed at containing the development costs of acquisition and operability of weapons systems are characterized by the involvement of experts from the production process and logistic support systems in the project engineering team, right from the earliest phases of the design process.

To these ends, Design for Manufacturing, Design to Cost, Concurrent Engineering, Integrated Product Development and Lean Manufacturing are amongst the principal techniques studied in recent years.

Experience has shown that certain conditions which facilitate and assure the success of these techniques in the control and reduction of costs, particularly in life cycle cost can be identified.

The product designer, as well as the production process and logistic system designers, must have reached a homogenous level of maturity in technological knowledge. The integrated project team must be fully capable of understanding all operational and manufacturing implications of the project design proposals.

The comparative analysis of possible design solutions conducted by the various departments that are involved in the specification, acquisition, production, product support, in a phase in which only a limited quantity of data is available, is the key to the success of these techniques. The consequent development should ensure a product which can be made to specification in the shortest time and with the lowest number of deviations, both due to production techniques studied and realized in advance and to a procurement process imposed prior to production; and the product can be supported by a logistic system designed in parallel and optimized in synergy with the product itself.

The success of this process will be related to the degree of reliability and knowledge of all the implications of the technological solutions necessary to achieve the programme requirements.

This approach, even if it requires a development investment prior to that of traditional processes, offers, in the analysis of coherent application of these techniques, a cost reduction for acquisition of some 20-30% with respect to programmes conducted in the traditional way; similar reductions can be achieved in operational support costs.

However, in complex programmes where development times are necessarily long and where the simultaneous development of new technologies is considerable, the advantages of these techniques tend to reduce, sometimes significantly.

The development of new technologies applied in a programme makes it difficult if not improbable that the technicians who define the phases successive to development can reliably foresee the implications of these technologies.

The long development times may give rise to problems of obsolescence of components, materials, productive tools and information technology

systems that were considered during the development. And these elements require important and expensive phases of industrialization, which inevitably reduce the anticipated economic advantages.

Similar considerations can be made for the efficiency of the application of process and project criteria whose function is to guarantee best operative support of the product and the economic possibility of introducing modifications and the development of system updates.

In complex, long timescale programmes, it is possible that the general technological development, different from that hypothesized at the beginning of the programme, proposes alternative more cost-effective solutions incompatible with the basic system developed.

FINAL CONSIDERATIONS.

The above mentioned considerations regarding those elements which condition the cost of a programme of acquisition and the operational support of a weapon system through its entire life show up how the combination of requirements complexity and technology development put into difficulty the various techniques aimed at limiting the costs themselves.

In the past, trade-offs between on one hand the acquisition of simple systems, characterized by a rapid development and a specialized operational efficiency and on the other hand systems which respond to sophisticated requirements, and thus long acquisition times but with wide operational efficiency, have been repeatedly performed; certainly, the conditioning of an extremely challenging operational scenario, with rapid and competitive technological evolution, has favoured the choice of complex programmes characterized by requisites with large performance steps. Efforts to contain system acquisition costs were mainly concentrated on the increase of volume produced.

In the current geopolitical situation, characterized by an operational scenario simplification, mainly in terms of the reduction of density of the threat, we begin to see a reduction in the requirements for advanced performance and numbers of necessary aircraft; this in turn implies a lower requirement for special technological development and leads us to concentrate attention on the non-recurring and recurring process costs and maintenance of the operational capacity during its life.

These conditions allow us to foresee, with respect to cost effectiveness in the medium term, the possibility in the future to counterbalance solutions based on a complex multirole systems, as designed during last several tens of years, with solutions based on simpler systems which can be rapidly acquired, presumably more specialized in their role but with greater affordable variability in their successive versions to cope with scenario changes.

There is no doubt that in both situations the technological evolution must be taken into consideration. In the case of a long term programme, the nature of the technological development needs to be foreseen at the beginning of the programme and must be followed during the process of development, merging with design definition, and consequently accepting burdensome phases of industrialization to avoid the technological obsolescence of the choice when series production begins.

In the second hypothesis, technological development needs to go ahead and to be organized in parallel and independent from the constraints of the programme and having available new elements for the mid life variants of the project or for new project as the scenario conditions require or can justify them.

In the trade-off between the two solutions, all the element of strategic cost management must be taken into consideration with their specific effectiveness.

With regard to contractual aspects, programmes which are simpler and substantially more reliable in their development could permit the use of a type of contract which is more suitable to the requirements of the customer without creating difficulty and adding an economic burden to the structure of industrial costs, thus permitting greater contractual flexibility in the various phases of the programme.

In the management of non-recurring development costs for the weapon system, the techniques of concurrent engineering and of integrated product development in the organization of the process, offer the best economic results in the simpler programmes, lightened in their basic development costs and in their critical equipment and sped up in their manufacture.

In the management of recurring costs, Lean Production techniques offer advantages substantially similar for both complex and simpler systems.

With regard to the costs of modification and update to the basic system, the complexity of the initial system conceptually implies a greater cost in the introduction of new technologies.

Simple systems, as previously mentioned, can be more flexible and more affordable in terms of modifications, and, on the other hand, implying initial lower investment costs, can be substituted by new systems. In these cases the utilization of non obsolete components of the old system can be cost-effective: this opportunity is not proposable for complex systems.

In conclusion, it is possible to state that in the near future, also from the strategic cost management point of view, there will be a new and increased interest in systems responding to simpler requirements and to shorter acquisition times: this approach will require presumably more single-role systems, but it will permit simple A/C systems probably uninhabited, the acquisition of which will profit by the maximum effectiveness of the modern cost control techniques and of the different contract typology; and, in the operational life, this systems can more easily utilize common logistic organizations and will be more affordable in upgrading.

Cost Effectiveness in UK Defence Procurement: The COEIA

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SUMMARY

The UK has recently adopted a process for obtaining the most cost effective equipment for its armed forces, known as the Combined Operational Effectiveness and Investment Appraisal (COEIA). The role that the COEIA fulfils in the current UK defence procurement practice is explained and compared with previous practices. An outline of the process of selecting a **Class Of Military** equipment by means of a Balance of Investment study is followed by a description of how to select the most cost effective **Type Of Equipment** within a class using a combination of investment appraisal and estimating the military effectiveness of the equipment. The investment appraisal process for an aircraft system is described in terms of selecting the alternative procurement options, defining the assumptions, examining the cost breakdown structure, discounting the expected cash flow and analysing the risks and uncertainties. The different mechanisms for measuring operational effectiveness are examined in order to explore the military benefit which is expected from the alternative options. In conclusion alternative ways of combining cost and effectiveness are illustrated graphically to show how the most cost effective option for the procurement could be derived.

LIST OF SYMBOLS

Ac, Bc	Cost values
Ae,Be	Effectiveness values
BoI	Balance of Investment
CDA	Centre for Defence Analysis
CDP	Chief of Defence Procurement
CDS	Chief of Defence Staff
COEA	Cost and Operational Effectiveness Analysis
COEIA	Combined Operational Effectiveness and Investment Appraisal
DERA	Defence Evaluation and Research Agency
DOAC	Defence Operational Analysis Centre
EAC	Equipment Approval Committee
IA	Investment Appraisal
ISD	In Service Date
L(y)	Expenditure (or Receipt) in year y
MDAL	Master Data and Assumption List
MOD	Ministry of Defence
MOD(PE)	Ministry of Defence Procurement Executive
MoE	Measure of Effectiveness
NPV	Net Present Value
OA	Operational Analysis
PFI	Private Finance Initiative
PUS	Permanent Under Secretary
PV	Present Value
r	Discount rate %
R&M	Reliability and Maintainability
RAF	Royal Air Force
RN	Royal Navy
SPS	Specialist Procurement Services
SR	Staff Requirement
VAT	Value Added Tax
VCDS	Vice Chief if Defence Staff
WLC	Whole Life Cost
Y	Final year of the period
y	Year number

1. INTRODUCTION

1.1 Different nations approach the selection of defence equipment in different ways, depending on the scale of their defence budgets, the diversity of their global responsibilities, the structure of their Armed Forces, and the capabilities of their defence industrial base. This paper is intended to show how the UK Ministry of defence has adapted its procurement processes to obtain capital equipment and facilities which are the best value for money for its armed forces. The name of the game is **"Cost Effectiveness"**, which can be defined as the process of obtaining the most effective defence equipment at the lowest affordable cost. In order to explain this process it necessary to start with the organisation of the UK's Ministry of Defence and its procurement policies, and then concentrate on the methodology at the heart of this process for maximising Cost Effectiveness, the **Combined Operational Effectiveness and Investment Appraisal (COEIA).** The COEIA has played a central part of UK defence equipment selection for approximately 4 years, and it is the opinion of many of the key players that the change has brought considerable improvements in the decision making process.

1.2 Although this paper draws on authoritative MOD documents, its judgements represent the personal view of the author which may not correspond with MOD policy. It should also be noted that the conduct of equipment procurement varies with time and with the individual characteristics of the equipment considered. Such variations are ignored in this paper, which looks at the overall procurement process and makes comparison with the previous, less structured procurement process, which operated until 1993. As with most new processes it has evolved over the years, and continues to evolve even now, and this paper only seeks to describe the operation of the COEIA in the MOD's procurement procedure. Important omissions from the COEIA are the issues of industrial, foreign and social policy. These crucial factors often contribute to a UK government decision on defence procurement, but are addressed by policy papers external to the COEIA. It is also important to note that the COEIA does

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not make decisions on the procurement route to be followed, it only **Provides Informed Advice** to the central committees and Ministers, who make decisions on the basis of UK Government Policy and the advice provided by the MOD.

2. BACKGROUND

2.1 The Armed Forces of the UK have evolved to three Services [Royal Navy (RN), Army and Royal Air Force (RAF)] operating in the sea, land and air environments. Historically, these Services have often disagreed over their respective responsibilities at the interfaces of these environments (marines, naval aviation and tactical air support) but it is now recognised that in virtually all major future operations by UK forces the land, sea and air elements of these forces will be interdependent. Accordingly, all future planning of policy, operations and procurement is done by a tri-service "purple" staff, and the politicians leading the Ministry all have tri-service responsibilities.

2.2 The higher organisation of the Ministry of Defence (see Figure 1) is headed by the Secretary of State, supported by two Ministers of State with responsibilities for the Armed Forces and for Defence Procurement. The Secretary of State is advised by the Chief of the Defence Staff (CDS) and the Permanent Under Secretary (PUS) who are respectively the senior Service officer and the senior civilian official and who present military and financial advice.

2.3 The Ministry of Defence is divided into three main groupings, the fighting Services, the Central Staffs and the Ministry of Defence (Procurement Executive) or MOD(PE). The Services are each headed by professional military officers who advise CDS on single-Service matters and are responsible for good organisation, morale and operational efficiency. They are also responsible through their various logistics organisations for the maintenance and support of equipment in service. The Central Staffs are a tri-service organisation jointly headed by the Vice Chief of the Defence Staff (VCDS) and the 2nd Permanent Under Secretary (PUS), and consist of two broad groupings with considerable overlap:

(1) Military officers from all three Services, who are jointly responsible for formulating future operational plans and policies and the consequent equipment requirements.

(2) A civilian organisation responsible for resource planning, financial management and civilian personnel management.

MOD(PE)'s task is to procure defence equipment and services to the performance required within approved costs and timescales, while achieving best value for money for the UK taxpayer. Hence, although the largely-civilian MOD(PE) has an important role in defence policy and planning and its head, the Chief of Defence Procurement (CDP), attends or is represented on the Defence Council and all its supporting senior committees, MOD(PE) is not responsible for the allocation of resources within the defence budget nor for determining operational requirements for equipment.

2.4 In order to put this paper in context, it should be noted that at the time of writing the author works within a newly created defence agency, Specialist Procurement Services (SPS), which is owned by CDP. SPS provides independent advice to CDP and the rest of MOD on a number of keys areas in the procurement of defence equipment by MOD(PE). An important part of its services is to provide the Cost Forecasting advice which is usually forms a key input to the COEIA process.

3. PAST PROCUREMENT PRACTICE

3.1 In the past, the UK procurement of military equipment tended to operate as a two-stage process:

Stage A: Specification and justification of the operational requirement by the Defence Staff,

Stage B: Selection by the Procurement Executive of the most-economical equipment to meet that requirement (see Figure 2).

Stage A

The Defence Staff directed operational research studies by its own intramural specialists and by the Defence Operational Analysis Centre (DOAC); now know as the Centre for Defence Analysis (CDA), which is a division of the Defence Evaluation and Research Agency (DERA). The object of the studies was to compare the cost effectiveness of alternative force mixes, to identify the classes of equipment which merited inclusion in the UK's future force mix. Following these studies the Defence Staff formulated, for each chosen class of equipment, a Staff Requirement (SR) specifying the equipment's necessary performance and characteristics.

Stage B

The PE then used Investment Appraisal to compare alternative procurement options which satisfied to Staff Requirement and to select the most economical option, taking account of procurement cost, in-service cost and risk.

3.2 In theory there was scope for constructive interaction between the Defence Staff and the Procurement Executive, which might together consider the cost and capability of alternative options for meeting a SR. The standard SR layout specifically invited contractors to consider whether large reductions in cost could be achieved by modest easing of some of the requirement's specifications. But in practice the Defence Staff and MOD(PE) faced in opposite directions, respectively towards fellow Servicemen in operational units, and towards fellow professional managers and engineers in the defence industry. Also MOD(PE) and industry were reluctant to debate Staff Requirements which the customer Services had already formulated and agreed, nor were the Defence Staff particularly receptive to civilian meddling with the essential characteristics of the equipment which they judged necessary to ensure victory.

4. CURRENT PROCUREMENT PRACTICE

4.1 Determining the Equipment Class

The first stage of the new procurement process, defined previously as Stage A above, "The Specification and justification of the operational requirement by the Defence Staff", now examines the range of military equipment that will be necessary to meet the types of operation specified in Defence Roles[4], as shown in Figure 3. The latter are defined in Defence Planning Assumptions after consultation between Government Ministers and their top advisors and form the cornerstone for existence of and operation of the UK Ministry

of Defence. The range of military equipment required is examined in a Balance of Investment (BoI) study or Force Mix Study, in which different classes of equipment, such as main battle tanks, attack helicopters, or ground attack aircraft, are all compared against their ability to meet the demands of the Defence Roles. The studies are structured to provide guidance on the most appropriate mix of equipment classes that are likely to generate the most effective military capability. Operational analysis of the equipment classes in agreed scenarios is used to provide measures of the military capability, while broad order of magnitude cost forecasts provide an indication of the magnitude of the required investment to acquire these equipment classes. A major constraint on the studies is the amount of money available in the defence budget for the years when the procurement is anticipated, and this provides an upper limit on the numbers of assets in the different equipment classes that can be afforded. Thus the BoI study only provides guidance on the classes of equipment most likely to meet the Defence Roles, and further detailed studies are needed to identify the most cost effective equipment type within the class of equipment. At this stage it is the task of the MOD central staffs to generate a Staff Requirement that outlines the expected performance of the equipment type and the probable number of individual assets that will need to be procured.

4.2 **Selecting the Equipment Type**

A review of the UK equipment procurement procedures in 1991 (the Buckley Report[1]) called for substantial changes to the decision-making machinery. In particular, it specified that in future proposals for equipment procurement should be accompanied, amongst others, by a cost-effectiveness report based on operational analysis and life cycle costs of agreed alternative options. The requirement for a cost-effectiveness report was prompted by the established procedure in US of requiring a Cost and Operational Effectiveness Analysis (COEA) to support key decisions by the Defence Acquisitions Board. However US procedures have not remained static and the COEA process has recently evolved to a formal "Analysis of Alternatives".

4.3 The UK policy for the introduction of cost-effectiveness studies into the procurement process takes account of the limitations on the resources which UK can apply to studies of cost and operational effectiveness, and of existing Treasury Guidance[2] on the economic appraisal of public expenditure. The latter indicates that all proposed public expenditure, on equipment, services or facilities, should be subject to rigorous investigation by means of an Investment Appraisal (IA), whereby all the proposed expenditure and its resulting material benefits are placed on a common financial basis using discounted cash flow techniques to determine the best possible return on the investment over the whole life of the equipment. From an MOD point of view the difficulty lies, not with determining the Whole Life Cost (WLC) of procuring and operating a piece of military equipment, but with placing a financial value on the material benefit and hence return on the investment, which should be provided by the new equipment. The problem is, how do you determine the financial benefit provided by a new class of equipment necessary to meet an agreed Task within a Defence Role, such a new aircraft for UK Air Defence, a new main battle tank to defend the Central European Region, or a new Frigate to patrol the North Atlantic approaches to the UK?

4.4 **The COEIA**

Accordingly, MOD has chosen to use a "Combined Operational Effectiveness and Investment Appraisal" (COEIA) which emphasises that investment appraisal guidelines remain in force and the military effectiveness of the new system in its specified Defence Role has been brought into the equation as a measurable alternative to the financial benefit which should be provided by the new system. The purpose and scope of a COEIA is summarised in MOD's Guidelines[3] to the EAC dossier system, where a COEIA is defined as a formal comparison of the cost effectiveness of a range of options to satisfy (wholly or partially) a military requirement. The COEIA therefore involves rigorous and objective quantification of the operational benefits of the competing options, as well as the traditional investment appraisal of their costs. Figure 4 illustrates the new procurement process to secure the most cost-effective procurement solution, emphasising the equal weight given to the Whole Life Costs and the operational effectiveness. The Guidelines[3] document also describes how the COEIA and the 6 other papers (shown in Figure 5) form the basis for the MOD decision making process for the procurement of defence equipment. The 7 papers collectively form what is know as a "Dossier", which provides a consolidated view of the MOD on the preferred solution to the operational requirement. The Dossier has to be approved by the MOD Equipment Approval Committee (EAC), who make recommendations to Ministers on the preferred procurement route, remembering that the COEIA only informs the decision making process.

4.5 It is expected that a COEIA will be done before each major milestone or decision point in an equipment procurement project, which involves either the commitment of substantial funds or the irrevocable abandonment of a procurement option. In practice this means that a COEIA tends to be undertaken 2 or possibly 3 times during the life of a project, and the scope and content of successive COEIA change as more detailed information becomes available, and as new options become available for consideration.

5. CONCEPT OF ANALYSIS FOR THE COEIA

5.1 Before work on a COEIA is begun, a concept of analysis must be formulated and approved by the relevant MOD branches. The concept of analysis must refer to the relevant force-mix studies which have provided justification for a particular class of equipment; it should then set out the alternative options to be examined within the class of equipment considered, the MOD-approved scenarios and concepts of operation to be considered, the measures of effectiveness to be employed, the assumed procurement and support strategy for each option, the methods to be used for estimating the whole life costs and the method of presentation of the final results.

5.2 The range of alternative options may include:

a) run-on existing equipment, with only normal maintenance and repair (this is described as the "do-nothing" option);

b) run-on existing equipment, with refurbishment when required to extend service life but with no change to the equipment's effectiveness;

c)procure or lease new [or second-hand] equipment, with broadly the same capability as the existing equipment, off-the-shelf;

d) upgrade existing equipment to enhance its capability and refurbish it as necessary to extend service life;

e) ask industry to suggest a mechanism for meeting the operational requirement by means of the Private Finance Initiative (PFI);

f) procure or lease new [or second-hand] equipment with improved capability off-the-shelf;

g) fund development and production of new equipment;

5.3 Option (d) may include several sub-options incorporating different levels of upgrade to part or all of the fleet. Options (f) and (g) may include many sub-options covering different designs of equipment in the appropriate class, a range of numbers of each design to be procured, and various procurement and support strategies in each case. The options can include a multirole equipment design capable of all the military operations cited in the Staff requirement, and a heterogeneous fleet of two or more specialist equipment designs, each with limited but complementary capabilities. The chosen range of options is inevitably a compromise between including all perceived solutions, excluding those solutions which are impractical (due to conflicting Service manpower constraints or national policies), and addressing only a number consistent with MOD's analytical resources. In all cases the selected options must include the do-nothing option and at least two others from (d), (e),(f), or (g) which meet the performance and/or effectiveness standards specified in the SR.

5.4 Option (e) has only been included recently to encompass the UK Government's directive that any new major expenditure should examine the cost effectiveness of acquiring the capability via the Private Finance Initiative (PFI), where private industry is asked to provide bids to the MOD for the provision of the service defined in the Staff Requirement. When PFI is deemed to be appropriate it is probable that one of the alternate options in the CoA would be to procure an identical capability using option (f) and use this option as the "Public Sector Comparator" against which the cost effectiveness of the PFI option would be judged. The inclusion of PFI bids in CoA for COEIAs has only just been developed and experience is very limited. The appropriateness of PFI for many classes of military equipment is not always obvious and each procurement case clearly has to be cleared by CDP and his staff before undertaking a COEIA which includes PFI.

5.5 The concept of analysis must acknowledge that the COEIA's result may well be determined by the choice of the measure (or measures) of equipment effectiveness. The choice is made particularly difficult because UK Armed Forces are only very rarely engaged in major conflicts which would enable the effectiveness of their capital stock of military equipment to be observed and quantified. In principle it is logical to follow MOD's traditional policy of measuring the benefits from new military equipment in terms of its effectiveness in future military engagements derived from agreed scenarios. In practice there is scope for debate on how victory in a military engagements is defined. It could be, for example, the attainment of specific objectives, a rate of advance or a favourable body-count. However it is defined, the probabilities of victory are dependent on scenario assumptions, tactics, etc, and may be insensitive (and hence poor discriminators) unless the opposing forces are evenly matched. Consequently it is common to measure the effectiveness of alternate equipment options by a weighted array of performance measures, chosen very carefully to avoid the introduction of bias. The inclusion of characteristics which are inconvenient to estimate, but may significantly influence effectiveness on the battlefield tend to be assessed via a Military Advisory Panel which would make qualitative judgements on the capabilities provided by the characteristics within the options.

5.6 MOD traditionally measures the cost of military equipment, including procurement, operations, support and disposal, in terms of its whole life cost in peacetime. This policy is consistent with the historic Cold War concept of deterrence, where military planning and procurement was directed towards resisting a Warsaw Pact attack on the NATO alliance. Success of the policy was clearly the absence of any attack. Today however, UK Forces are routinely deployed on a variety of military tasks, in support of the Defence Roles shown in Figure 3, some of which may involve protracted peacekeeping operations. The cost of these operations depends on their remoteness from UK, the scale of the UK Forces involved, and the level of opposition which they confront. From a narrow MOD perspective these costs may be ignored if it can be assumed that they will be met by an additional grant from the Treasury or by contributions from foreign Governments. Hence the policy of measuring equipment cost in peacetime remains in force.

5.7 The period addressed by a COEIA should begin at the point when the relevant procurement decision takes effect, and should end some 25 years later to correspond approximately with the life span of major items of military equipment. If a longer time-span is chosen, it extends into a period where it becomes impossibly-difficult to predict the consequences for force cost and force effectiveness of selecting for procurement one of the several alternatives considered. If a shorter time-span is chosen, the results may be dominated by the residual values of equipment at the end of the period (see Disposal below).

6. COEIA - INVESTMENT APPRAISAL

6.1 Investment Appraisal provides a structured method of assessing all the costs, benefits and risks associated with alternative decisions on public expenditure. The principles and procedures of investment appraisal by UK government departments have been described by a HM Treasury Guide[2]. In MOD, investment appraisals can be used to assess alternative logistics or asset management policies as well as in equipment procurement, but only the latter aspect is considered below.

6.2 The key factors of the investment appraisal part of a COEIA are:

a) a rigorous and comprehensive description of each of the options considered, noting all the relevant technical and economic data, assumptions and all factors relevant to the option cost

b) estimates of all the components of the Whole Life Cost of each of the alternative options; the costs in future years should be discounted using the Treasury rate. See Annex A for a description of the cost breakdown structure of an aircraft option.

c) assessment of the financial and other risks associated with the alternative options

d) discussion of those advantages and disadvantages of different options which cannot be expressed in terms of money.

6.3 The MDAL

The descriptions of the equipment options are embodied in a Master Data and Assumptions List (MDAL) which must be approved by all relevant MOD branches before definitive cost forecasting begins. The MDAL includes:

a) a complete technical description of each of the options (noting in particular any non-standard features),

b) a definition of the procurement strategy and the development and production plans of the various contractors involved

c) the delivery schedule and the associated establishment of operational units, policies for these units' deployment, training and logistics and plans for procurement of the associated infrastructure and support equipment

d) assumptions on the intensity of operations and on equipment R&M, and consequent estimates of the levels of Service and/or civilian manpower required for operations, support, etc.

e) broad indications of the methods to be employed to cost the elements included in the Cost Breakdown Structure, such as that shown in Annex A.

The generation of a MDAL involves considerable discussion and debate to ensure that all key assumptions have been addressed, that each option forms a self-consistent entity, and that all options are on a level playing field without inequitable benefits or penalties.

6.4 Discounted cash flow

It is normal in MOD to express future costs in real terms, at a given set of prices corresponding to a particular date, which is usually taken to be the middle of the current or preceding Financial Year (known as the baseline year or y=0). If costs are calculated for, or are available from earlier years, then they are adjusted to a common price level at the baseline year by taking into account the actual price changes for the labour, materials and services involved in the procurement and in-service cost of the equipment. However **no allowance is made for inflation** of prices in future years beyond the baseline year. It is also normal to exclude "sunk" costs which have already been incurred or irretrievably committed, since these costs cannot be affected by the result of the COEIA.

6.5 The forecast expenditure (or receipts) for each option is generally distributed across the period chosen for the IA, starting with the baseline year, y=0 and finishing at y=Y, with different options having different expenditure profiles. Expenditure in different years cannot be compared directly because individuals and organisations recognise the time value of money and prefer to receive cash sooner rather than later and to pay bills later rather than sooner; this time value remains even if inflation is zero. Expenditure (or receipt) of an amount L(y) in year y may be put on the same basis as year zero by applying a discount factor to future expenditure, creating the Present Value (PV) of the expenditure in year y.

$$PV = L(y) / (1 + r)^y,$$

where r is the real discount rate, currently specified by HM Treasury to be r=6%. The Net Present Value (NPV) of future expenditure and receipts is the summation of the discounted values

$$NPV = \sum_0^Y L(y) / (1 + r)^y.$$

6.6 Common items

Since all options refer to the same class of equipment, it is unnecessary to include costs which would be common for all the alternative options. For example, if it were planned that all the options would be deployed to the same operating bases and would use the same maintenance base for major servicing, then the fixed costs of these bases need not be included in the IA.

6.7 Taxes and subsidies

In principle, investment appraisals may consider expenditure either at market prices or at factor cost (i.e. excluding indirect taxes and subsidies). The Treasury Guide[2] directs that options attracting different Value Added Tax (VAT) conventions should be assessed on a consistent basis. Since VAT conventions on military equipment vary with the nature and origin of the equipment options considered, MOD IA normally exclude VAT. The Guide[2] also stipulates that macroeconomic benefits to the Treasury from employment effects, generating more taxes and lower benefits, should not be generally included since such benefits arise from the overall level of government expenditure rather than from a particular equipment procurement project.

6.8 Disposal

For a COEIA covering an agreed period, it is implicitly assumed that the military capability is required up to the end of the period, after which the equipment goes for disposal. This notional convention is not reflected in reality, but it is included for comparison between options, some of which may be able to sustain a useful military capability long after the point of disposal. It is therefore necessary to estimate the revenue from sales or the costs of disposal of equipment at the

end of the period; this revenue or cost constitutes the residual value. There are many ways of estimating residual value, such as a linear depreciation from the initial procurement cost from the date of procurement to the end of the agreed period or a fixed percentage annual depreciation. The choice will depend on the nature of the equipment and the commercial market place for disposal. Fortunately it is unnecessary for these estimates to be very accurate, since the discount factor ensures that they are much less important than similar revenue or costs at the beginning of the COEIA period.

6.9 **Risk and uncertainty**

At the start of a procurement programme MOD cannot be sure that the final performance of the equipment, and the timescale and cost of its procurement, will be as predicted. Many of these uncertainties will not be resolved until service trials are complete and the procurement bills are paid, but uncertainties about operating and support cost can persist through the equipment's service life. Consequently the cost forecasting process can never be an exact science, even if one has, for example, manufacturer's bids on the table for the all the options defined in the MDAL. Frequently the bids will only cover the development and procurement costs, which make up the majority of the up front acquisition costs. However one of the largest contributions to the whole life costs, tends to be the operating and support costs throughout the in-service life of the equipment and this usually has to be estimated by MOD rather than the manufacturers. This may change in the future as the in-service support authorities explore the prospect of contractor aided support or full contractor support, for which bids may be ultimately be provided. At time of writing however, most cost forecasts are a forward projection based on the performance of past projects, which is tempered by expert knowledge of the way industry has changed its processes since the most recent similar procurement. As a consequence there is always a degree of uncertainty in any forecasts, which can be estimated from the distribution of results produced by any Cost Estimating Relationship employed. Figure 6 shows a theoretical plot of performance versus cost for a range of equipment numbers, which illustrates of the effects of uncertainty. This provides the first level of uncertainty in any costs generated for an IA.

6.10 Uncertainties in costs and timescales can also arise from:

a) The unknown outcome of engineering trials during development,
b) Financial or industrial developments affecting the equipment contractors concerned,
c) Underdeveloped projects with glossy brochures from inexperienced contractors, compared with off-the-shelf procurement from an honest and trustworthy contractor, offering fixed prices and long-term guarantees,
d) The impulses of powerful officers and politicians who can influence the course of the procurement.

In order to distinguish them from the cost estimating uncertainty described above, these uncertainties will be categorised as **risks.** The IA should include a judicious analysis of these risks and their likely impact on the final performance, timescale and cost of the equipment considered. This will normally take the form of sensitivity tests to examine the variation of the IA to the identified risk items. A likely outcome of risk analysis is an increase in the cost for a given performance or a reduction of performance for a given cost. This is illustrated in Figure 7, where the shaded area shows the error bounds for a single point estimate on the introduction of likely risk elements.

7. **COEIA - OPERATIONAL EFFECTIVENESS**

7.1 Within a COEIA, the operational research studies seek to assess the effectiveness in future military operations of each alternative equipment option. However before embarking on a study of operational effectiveness, it is first necessary to forecast the most likely performance of new equipment (which has sometimes not yet been developed) against the equipment deployed by or on order for potentially-hostile nations. Such technological forecasts are generated by the Defence Evaluation and Research Agency (DERA) based on its current research programme, and intelligence information about equipment being developed elsewhere. The assessment of operational effectiveness tends to be made three alternative methods, which depend on the type of military equipment to be procured. These are **a comparison with minimum criteria, a scoring system and Operational analysis**, which will be considered in turn.

7.2 **Comparison with minimum criteria**

The simplest approach to equipment assessment would be to:

a) List all the attributes of the class of equipment which contribute to its operational effectiveness,
b) Set minimum acceptable levels for each attribute,
c) Compare each option with the list,
d) Exclude those options which fail to achieve the minimum standards in one or more criteria,
e) Regard the remaining options as operationally equivalent.

Unfortunately this approach has the disadvantage that even relatively-simple military systems have a large number of relevant performance criteria, and complex systems would be unmanageable. Unless the minimum criteria are set very low, some options which are generally acceptable could be excluded by falling short of a very few criteria. In addition there is no mechanism for trading off strengths and weaknesses of alternate options and there is no credit for options outperforming the minimum criteria.

7.3 **Scoring system**

Another approach is to list all the attributes of the class of equipment which contribute to its operational effectiveness, as in (1) above, and to set up a weighting and scoring system for the attributes so that an option's strengths and weaknesses can be synthesised into a single overall score by linear combination of the scores. Although this approach has the virtue of consistency across the alternative equipment options it has a number of disadvantages:
a) Most weighting factors, and all scores derived from qualitative characteristics, are highly subjective.
b) Concentrating heavily on the attributes of the options can present difficulties when the score for an attribute depends heavily on interactions with other units, particularly enemy units.

c) Aggregation by linear weighting cannot account for interactions between the attributes of the equipment, for example manoeuvrability, weapon load and fuel capacity are critical attributes of an air defence fighter, which cannot be combined linearly.
d) It can only compare one system with another, and cannot address the advantages of many low-cost systems relative to a few expensive ones.

7.4 Operational Analysis

The third method uses high level military operational analysis (OA) to evaluate explicitly and quantitatively the overall performance of the equipment options using battle modelling techniques. In practice the UK uses a number of standardised battle scenarios for the use of UK forces, based on possible future conflicts in agreed Defence Roles. A Military Advisory Panel would be convened to provide detailed guidance on the use of the military equipment committed under the scenario. Ideally the OA would yield a single measure of equipment effectiveness (MoE) across all scenarios, and has been assumed for clarity in all the examples in this paper. However, in practice the outcome of military operations can be assessed from several perspectives and the OA results may have to be expressed as a small set of MoEs applicable across the range of applicable scenarios, e.g. an MoE for Air Combat Effectiveness and an MoE for Offensive Support Effectiveness in the case of a new combat aircraft. In addition there are often equipment characteristics (such as multirole capability, mobility between theatres and logistics) whose value may not be fully reflected in individual scenarios and would be considered in the top level evaluation of concurrent scenarios, where all individual MoEs would be aggregated as a single MoE for the option being considered. Thus the OA approach reduces but does not entirely remove the problem of assessing equipment in terms of multiple parameters, and it replaces the subjectivity of a scoring and weighting system by the uncertainty of scenario assumptions about enemy and allied weapons and tactics, terrain, combat degradation, etc.

7.5 The effectiveness of a combat equipment option tends to vary with time across the COEIA period for two main reasons:

1. Each of the alternative procurement options will exhibit its own variation of effectiveness, which is dictated by the In Service Date (ISD) and delivery profile of the new equipment,
2. There is a slow degradation of effectiveness as the relevant enemy equipment is upgraded or replaced.

The former tends to generate gaps in effectiveness, which may or may not be politically acceptable, while the latter tends to be the driving force for period replacement of existing equipment. Because the timing of any conflict which would make use of this equipment is usually unpredictable, the impact of this effectiveness time profile is difficult to judge objectively. Unless there is hard evidence available on the impact of the effectiveness time profile, such as the political unacceptability of no capability for a number of years, it would be plausible and realistic to use a discount factor to discount effectiveness in future years. To a first approximation this would match the slow degradation created by the improvement of enemy equipment and could be modelled with a discount factor of the same magnitude as that used to discount costs. A number of major COEIAs have adopted discounting to compensate for major differences in ISD between off the shelf and newly developed equipment.

8. PRESENTATION OF RESULTS

8.1 The effectiveness assessments and cost forecasts for the alternative equipment options now have to be compared to establish the optimum cost effectiveness. Principles of Cost Effectiveness Analysis[5] have recently been issued for guidance to the COEIA practitioners, and a number of its points are worth exploring. A major point is that cost effectiveness is not an absolute quantity, it is a relative measurement of two or more alternative options which provide a military capability. In the case of two alternative investments A and B, each with known cost (Ac and Bc) and effectiveness (Ae and Be), **A is more cost-effective than B if**

(Ae >= Be) AND (Ac <=Bc).

This is illustrated in the 2 dimensional diagram of effectiveness versus cost of Figure 8, where effectiveness is the vertical axis and cost the horizontal axis. Using these axes the most cost effective option is always the one closest to the top left of the diagram.

8.2 Cost and effectiveness can be treated as two independent measurements of alternative military options. If the characterstics of the option allow a range of equipment quantities to be procured, each quantity will have an associated cost and effectiveness which can be represented by a point on the effectiveness, cost diagram. Figure 9 shows the locus of these points for two different options. The plots are idealised and assume that zero effectiveness is provided at zero cost in both cases. Both curves have the same shape, which resembles the letter "S". The reasoning behind this shape is as follows:

1) For low numbers of equipment the military capability is not significant until a critical threshold is acquired, thereafter the effectiveness increases linearly,
2) For large numbers of equipment the military capability becomes saturated and increasing the quantity makes little impact on the measure of effectiveness resulting in a knee in the curve.

A consequence of this shape is that it is dangerous to rely on the ratio (Effectiveness/Cost) for any given quantity of equipment. For example the straight line on Figure 9 has constant ratio of (Effectiveness/Cost), and all four points P1, Q1, P2 and Q2 have the same ratio, even though option 1 is the most cost effective solution according to the definition given above. It is thus dangerous to rely purely on the effectiveness/cost ratio for specific quantities of equipment as a measure of cost effectiveness.

8.3 The way to avoid such ambiguities is to arrange for all analysis to be undertaken around one of two primary conditions:

1. determine which option yields the lowest discounted life cycle cost for a specified level of effectiveness (constant effectiveness),

OR

2. determine which option yields the greatest effectiveness

for a specified discounted level of life cycle cost (constant cost).

This is illustrated in Figure 10 using the same two options shown in Figure 9. In the case of constant effectiveness, point P1 is clearly cheaper than point P2 and so option 1 represents the most cost effective solution. Whereas for constant cost, point Q1 has a greater effectiveness than point P2 and option 1 still represents the most cost effective solution. Either method is suitable for analysis and the choice is usually driven by the detailed nature of the military equipment required. As a general rule the UK tends to prefer analysis at constant cost on the basis that it is easier to set up and start with options that have the same whole life cost. With the proviso that a suitable range of equipment numbers can be specified at the start of the COEIA process, the cost forecasting process can be faster than the equivalent operational analysis process. The equipment numbers at the start of a COEIA are frequently constrained by other factors, the most important of which would be the budgetary allocation for the whole procurement project set by MOD's the Long Term Costing process.

8.4 In practice however it is rarely possible to reduce an intrinsically two-dimensional problem of cost effectiveness to a single scalar point on a graph. As already explained uncertainty will expand the cost and effectiveness points into an ellipse, within which the most likely solution will lie. If any of these ellipses intersect, as shown in Figure 11, then there is no clear cut "most cost-effective" answer. In this case the uncertainty ellipses of points P1 and P2 in the constant effectiveness case overlap and it is not conclusive that option 1 is more cost effective than option 2. For the constant cost case the uncertainty ellipses of points Q1 and Q2 touch and there is only a high probability is that option 1 is the more cost effective option.

8.5 A typical COEIA, but with a simplified number of options to avoid confusion, is shown in Figure 12, where the presence of uncertainty is represented by the finite size of the symbols. The decision-maker thus faces an array of points representing the alternative options in cost-effectiveness space. Options which involve running-on or upgrading existing equipment can rarely attain the effectiveness of options involving new equipment and within each option the variation of force effectiveness with force cost is not continuous as the numbers of equipment are increased, but jumps as another military unit is formed or as another base is activated. In this particular case the new equipment looks like the best value for money, but its advantage could be eroded if the development programme went badly or if part of the expected budget was withdrawn. The final example in Figure 13 shows a simplified version of recent COEIA, where it was possible to generate meaningful plots of cost and effectiveness. For obvious reasons the scales and details of the options have been omitted. MOD's eventual selection of an option must take into account a number of requirements:

a) to achieve an acceptable level of force effectiveness, the Target Performance,

b) to remain within the available budget,

c) to accord with possible constraints on Service manpower and training facilities,

d) to minimise risk,

and above all

e) to obtain the best value for money.

9. PRACTICAL APPLICATION OF COEIA

9.1 It is not possible to provide any detailed information on recent procurement decisions where the COEIA process has played a fundamental role, because of the political and industrial sensitivity of the decisions. It is however possible to indicate which major equipment procurement decisions have been guided by the results of a COEIA. On the aircraft side of MOD, COEIAs have been generated for the following major procurements:

EuroFighter 2000 for the RAF, to justify entering the Production Investment phase of the procurement,

Replacement Maritime Patrol Aircraft for the RAF, to aid the selection of the preferred system and bidder,

Attack Helicopter for the Army, to aid the selection of the preferred bidder,

Support Helicopter for the Army, to aid the selection of the preferred bidder,

Tornado F3 capability update, to evaluate alternative options to the update,

C130 Hercules replacement, to aid the selection of a procurement strategy and suggest a preferred bid,

Replacement Carrier Borne Aircraft for the RN, to verify the chosen procurement strategy,

Future Offensive Aircraft for the RAF, to examine the results of pre-feasibility studies.

This not an exclusive list, but it does perhaps give a flavour of the UK procurement decisions in recent years where a COEIA has played an important part. Without being specific it is worth emphasising that in some cases the final Ministerial decision on preferred bids or options did not always accord with the results of the COEIA. Other factors were brought into play that were judged politically more important, such as the maintenance of the UK industrial capability and ensuring the greatest level of employment in the UK. It is left to the reader to judge which of these procurements fit into this category.

10. CONCLUDING REMARKS

10.1 The adoption of COEIA by MOD has not been without difficulties and misunderstandings. The instruction that COEIA should be included in future proposals for equipment procurement was not accompanied by any additional allowances in funding or timescale for current projects. Indeed it has been accompanied by continued pressure to reduce MOD's running costs and manpower. Furthermore, the situation has been complicated by an evolving turf battle within MOD between the Central Staffs and the Procurement Executive, each arguing that it should lead any COEIA. It harks back to the original procurement process where

a) the Defence Staffs are concerned with the effectiveness of future Service equipment,

b) the Procurement Executive are concerned with the procurement of defence equipment.

It is fair to say that there are sound arguments still being advanced on both sides, but in practice MOD operates a dual-key system, in which **both parties must be involved** in managing the COEIA and **both must accept its conclusions**. The process is slowly maturing and is increasing the mutual understanding between the various MOD communities of project managers, cost analysts, operational analysts, Service

operations and support branches and the various branches of the Central Staffs.

10.2 COEIA has sometimes been portrayed as a panacea able to remove all difficulties from the process of equipment selection. In reality it is a structured approach to a complex selection problem, which provides a framework for debating the technical, military and financial issues involved. The inputs to COEIA must rely on expert judgements, and the outputs must be considered in parallel with those factors which are inevitably omitted from all but the most sophisticated battle models. Thus COEIA do not supplant military and technical judgement, but rather supplement and reinforce it in selecting the most cost-effective equipment for MOD.

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ANNEX A

Major Elements Of Whole Life Costs For An Aircraft Cost Forecast

The Cost Breakdown Structure

1 Concept Studies

2 Feasibility Studies

3 Project Definition

4 Development

4.1 Full scale development
4.2 Software and hardware development rigs
4.3 Fatigue testing
4.4 * Amortised cost of the above per aircraft as a levy
4.5 Military Certificate of Airworthiness testing
4.6 Technical publications

5 Production

5.1 Production Investment (PI), Non-recurring Production costs
5.2 Production recurring costs
 5.2.1 Airframe
 5.2.2 Engine
 5.2.3 Avionics
 5.2.4 Special to type role equipment
5.3 Simulators and Training equipment for aircrew and ground crew
5.4 * UK specific modification costs
5.5 Airbase modification/construction
5.6 Works services for ground support/training equipment
5.7 Initial Procurement (IP) of spares for first 2 years in-service
5.8 Spare Engines and engine modules
5.9 Ground Support Equipment (GSE)
5.10 Special to type test equipment (STTE)
5.11 Contractor financing overheads for performance retentions relating to R&M conditions

The above items make up the TOTAL ACQUISITION COSTS

6 Operating And Support

6.1 In-service aircrew
6.2 Fuel and consumables
6.3 Maintenance and Repairs
6.4 Station overheads
6.5 Post Design Services (PDS)
6.6 Software Support
6.7 Accident Enquiry & Defect Investigation Team, AEDIT
6.8 Mid-Life Updates
6.9 Ageing aircraft allowance

The remaining items above make up the OPERATING AND SUPPORT COSTS

7 Disposal

7.1 Disposal
7.2 Residual value of equipment at end of IA period

Note: Items prefixed with a * are for foreign sourced equipment which might apply to an Off-The-Shelf procurement.

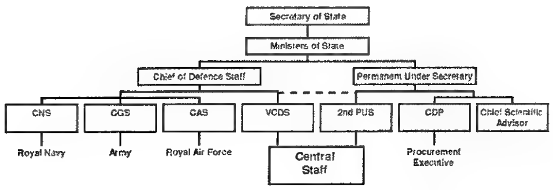

Figure 1 The Higher organisation of the UK Ministry of Defence

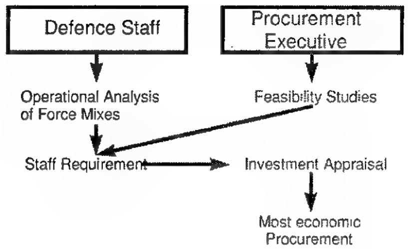

Figure 2 Old Procurement Procedure

DEFENCE ROLE	TYPE	DESCRIPTION
1	I	Military Aid to a Civilian Power
	II	Security of a Dependent Territory
2	III	General War
	IV	Regional Conflict
3	IV½ & V	Regional Conflict outside NATO
	VI	Other Assistance (UN)

Figure 3 Types of Operation

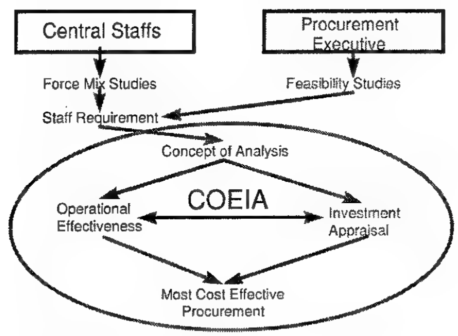

Figure 4 New Procurement Procedure

No.	TITLE	ORIGIN
1	Covering paper	Central Staff
2	Requirement Definition	Central Staff
3	COEIA	Central Staff & MOD(PE)
4	Procurement Issues	MOD(PE)
5	Programme Baseline	MOD(PE)
6	Support Strategy	Operating Service
7	Project Validity and Affordability	Central Staff

Figure 5 Equipment Approval Committee (EAC) Dossier components

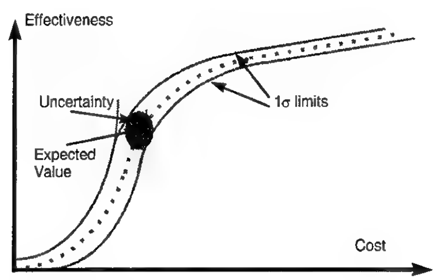

Figure 6 Uncertainty

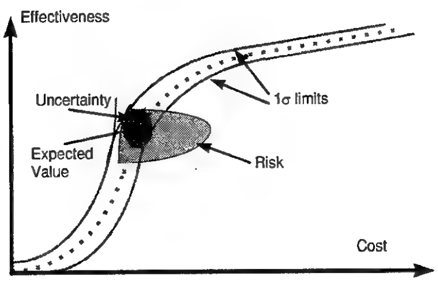

Figure 7 Uncertainty & Risk

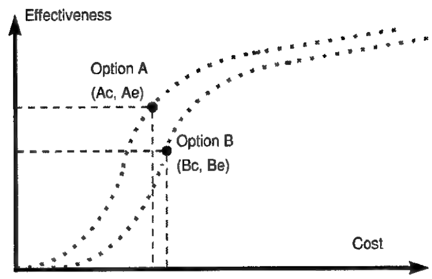

Figure 8 Definition of Cost Effectiveness

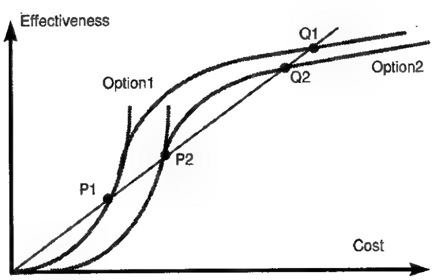

Figure 9 Effectiveness/Cost Ratio

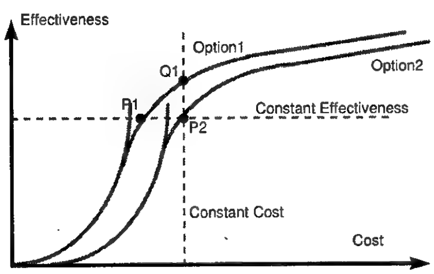

Figure 10 Optimum Cost Effectiveness

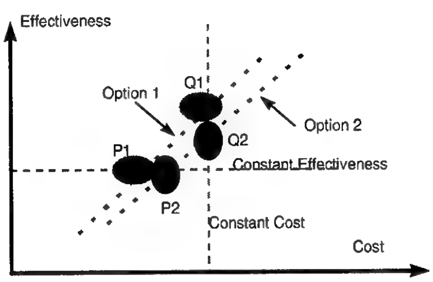

Figure 11 Comparison of Options With Uncertainty

Typical COEIA Results

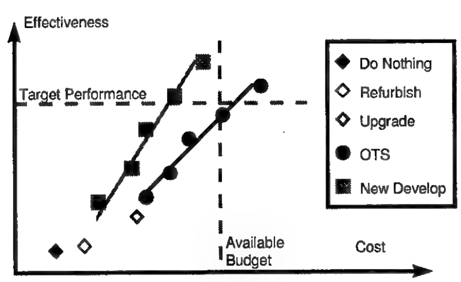

Figure 12 Typical COEIA Results

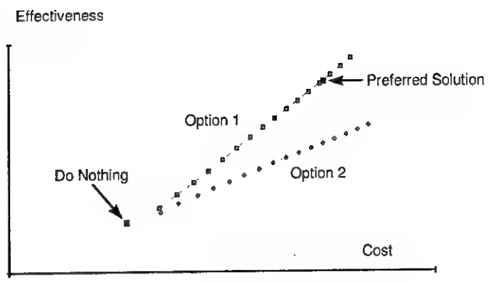

Figure 13 An Example COEIA

FIGURE CAPTIONS

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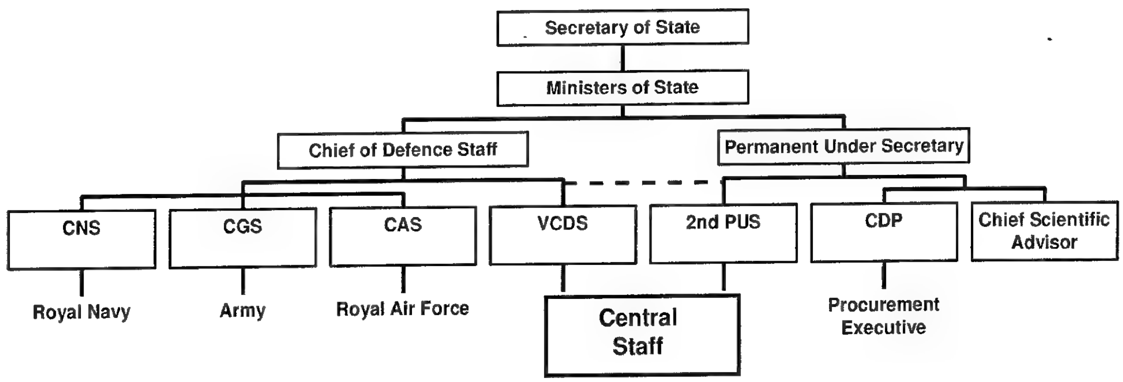
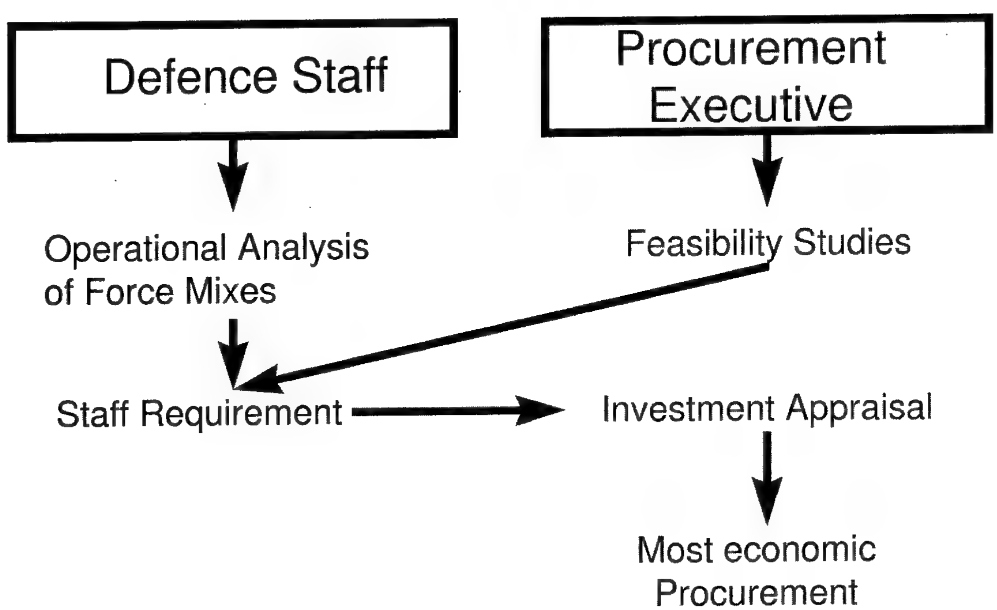


Figure 2. Old Procurement Procedure



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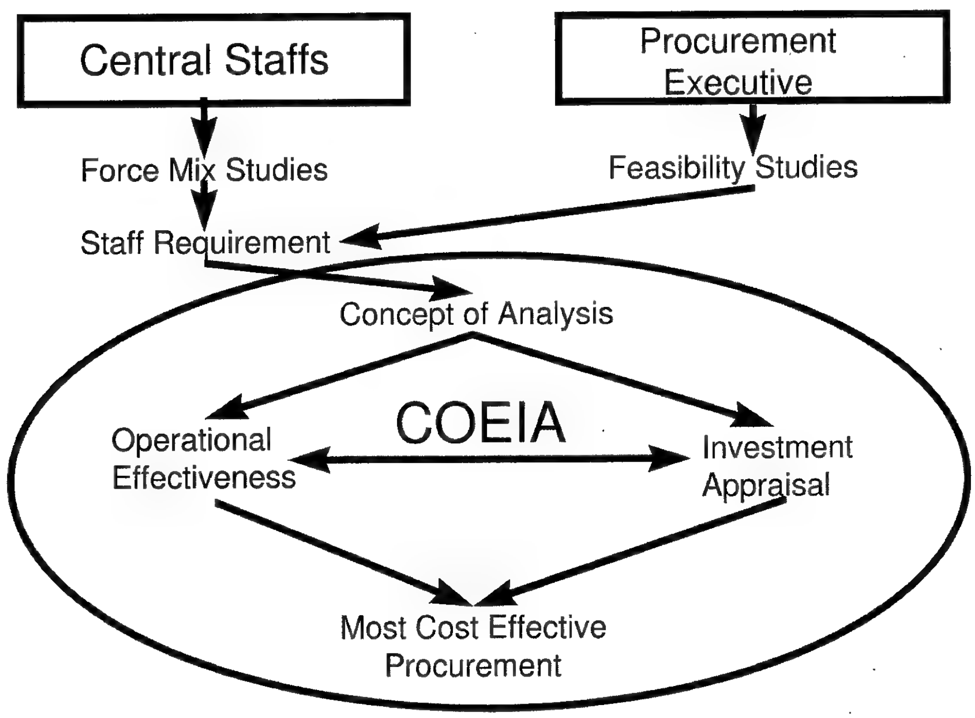

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Figure 6. Uncertainty

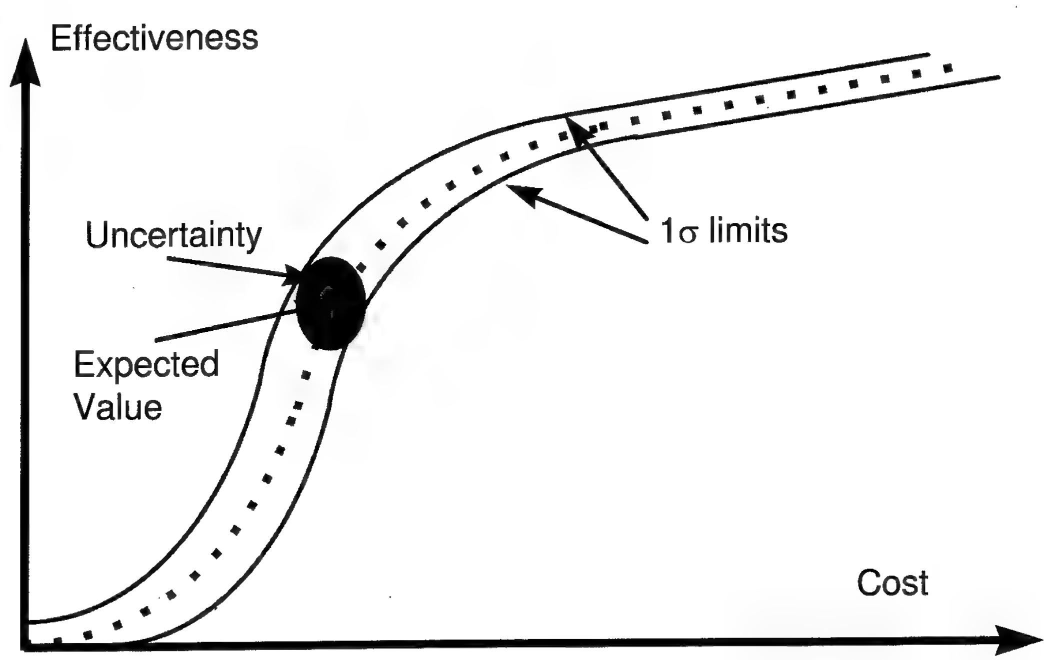
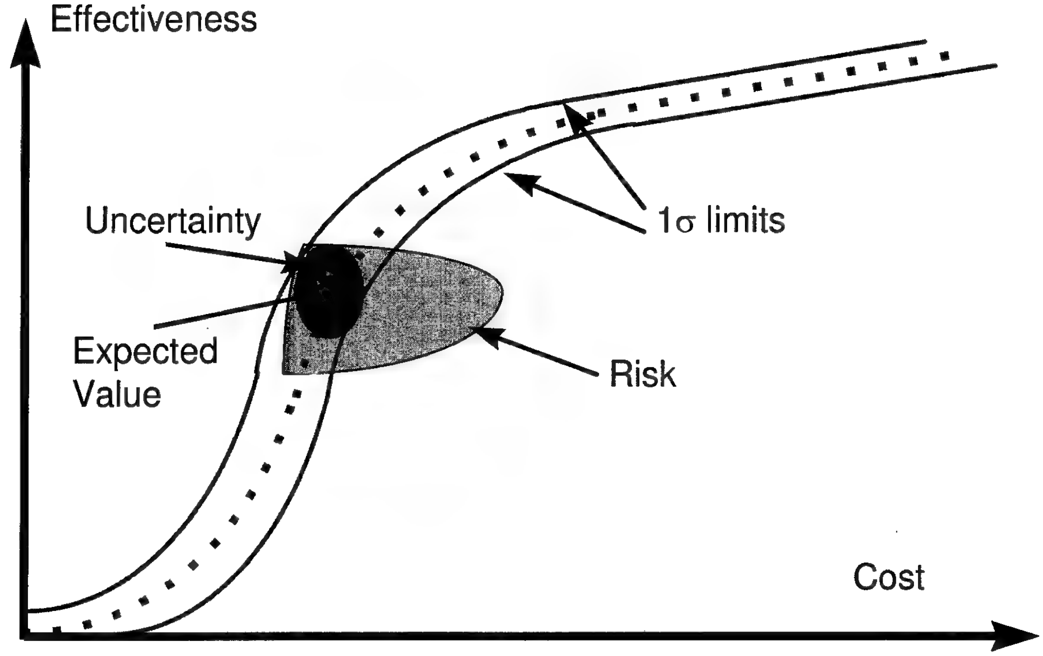


Figure 7. Uncertainty & Risk



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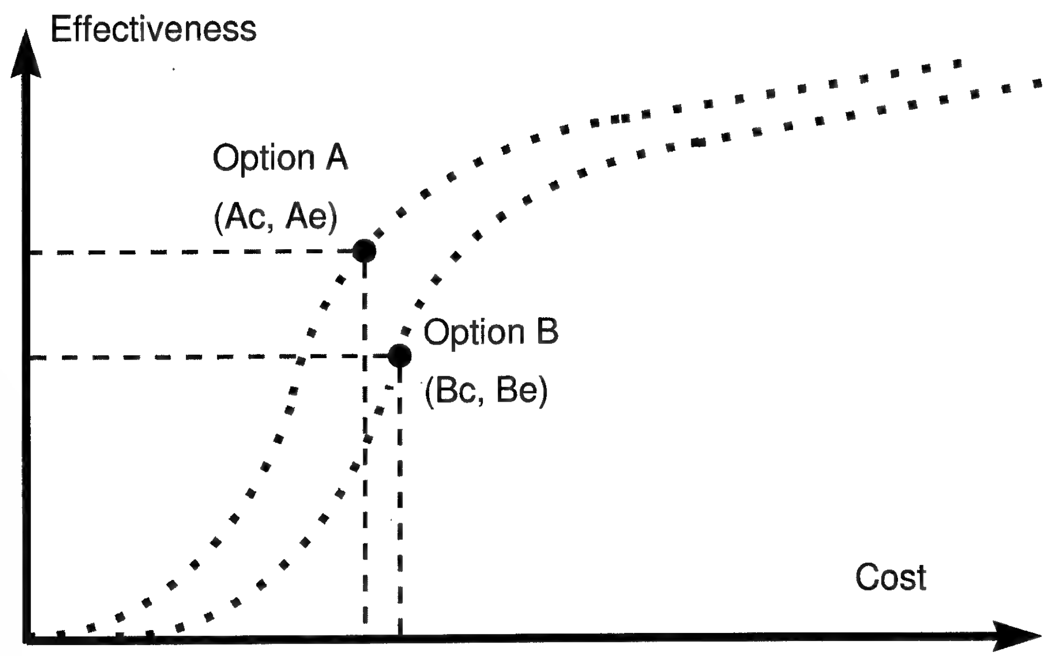

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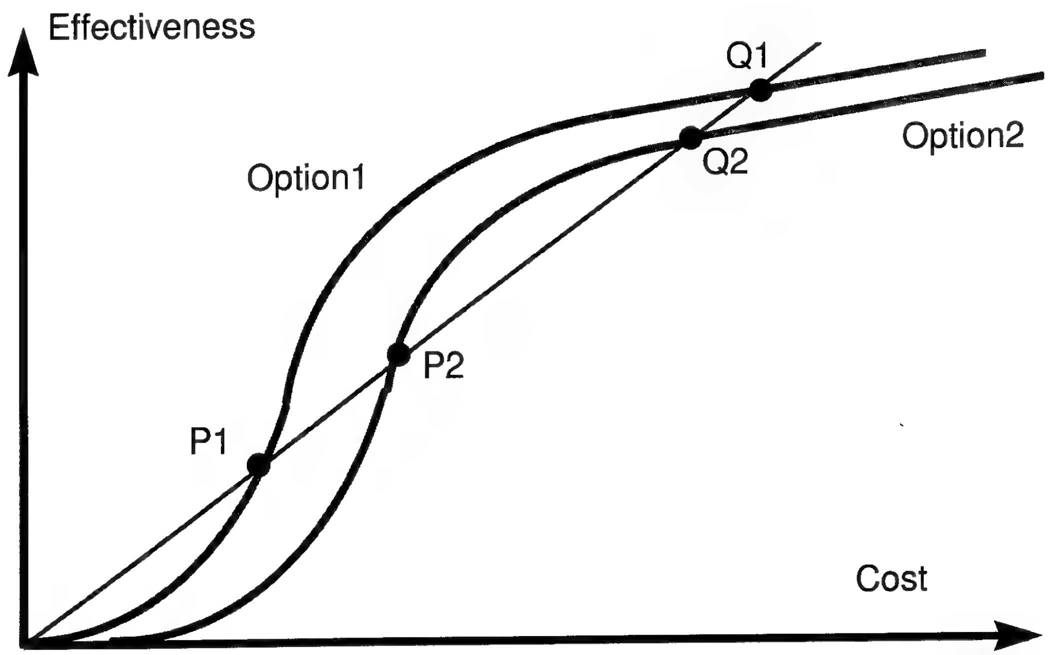

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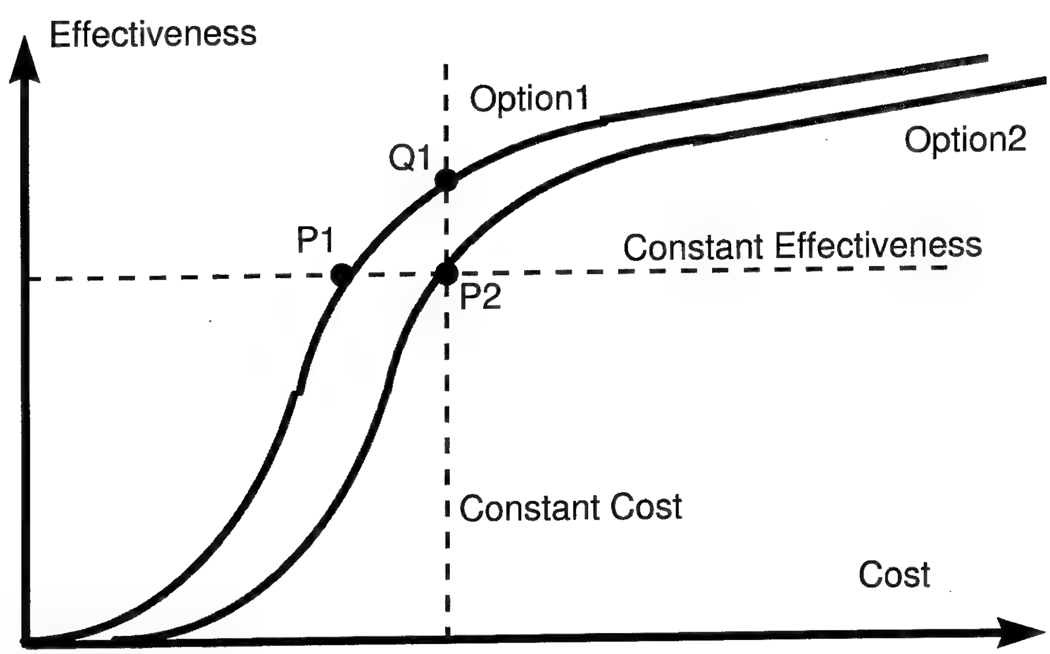

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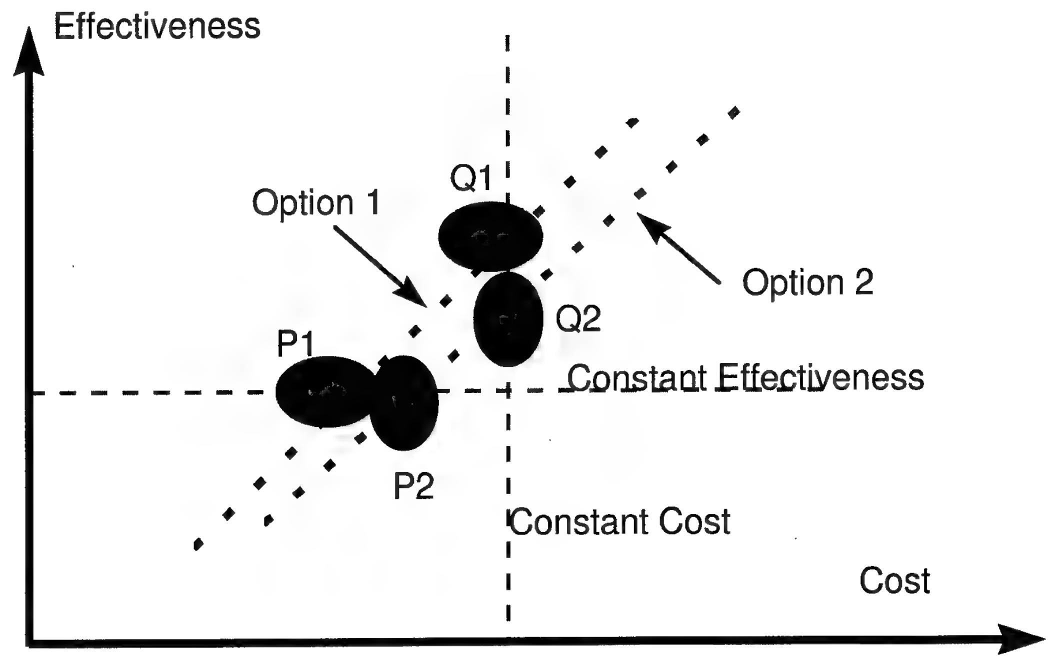

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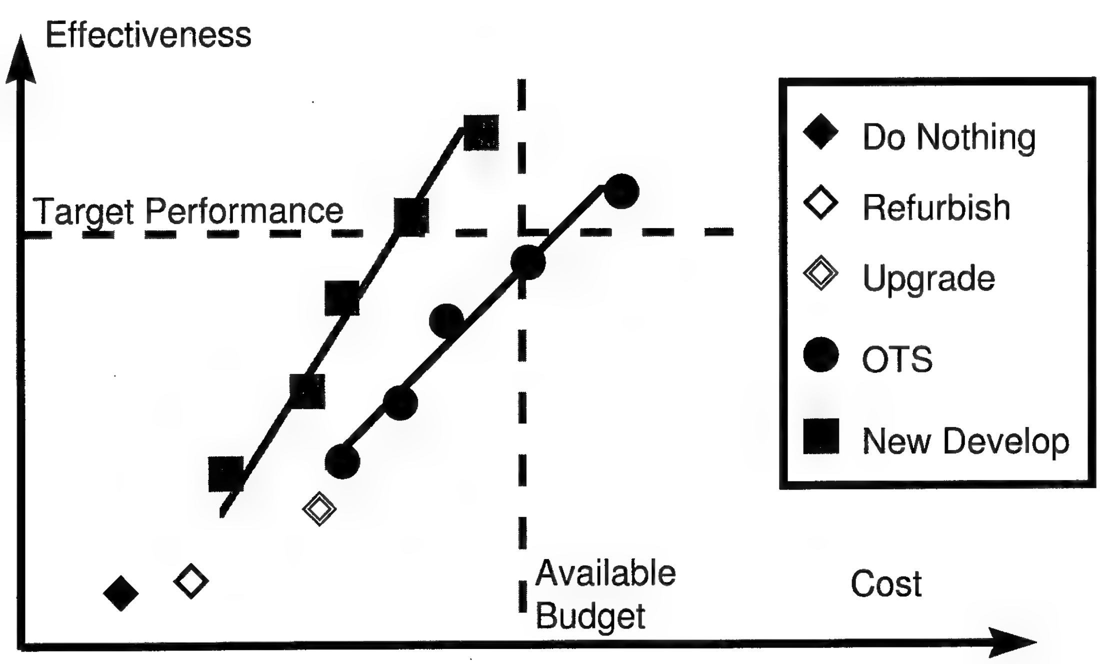

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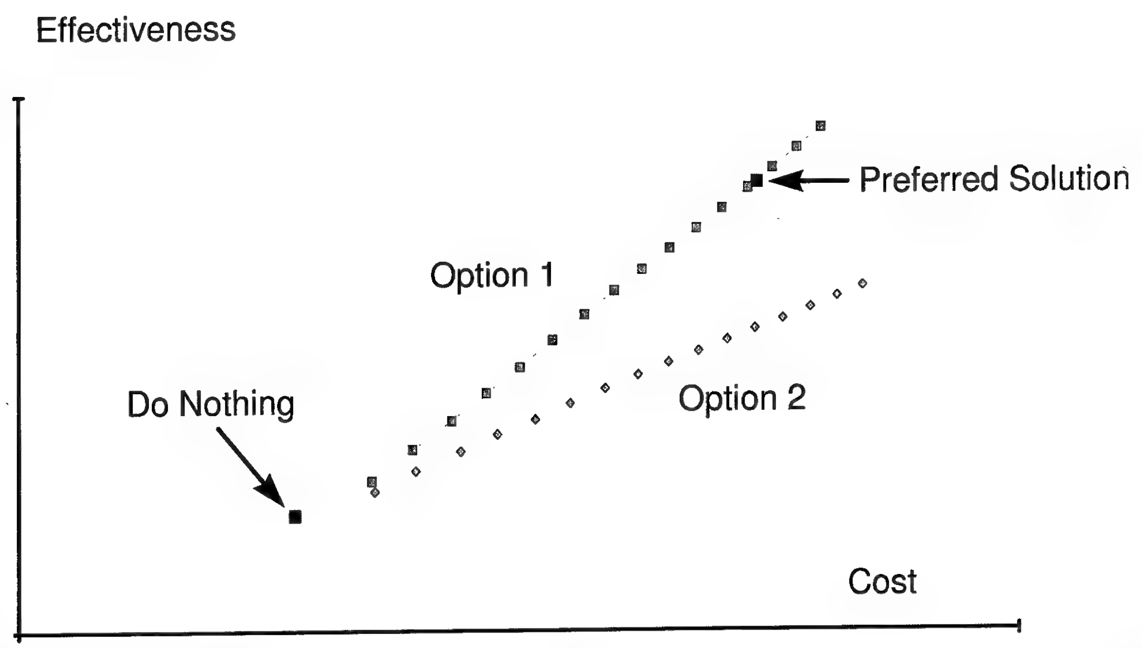

THE FUTURE FOR COMBAT AIRCRAFT DESIGN - AN INDUSTRIAL VIEW

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SUMMARY

The paper addresses the design and technology drivers which are likely to have the most impact on the next generation of combat aircraft from an industrial perspective. The nature of future conflicts and the emerging threats are becoming increasingly difficult to predict, and operational needs stress the growing importance of flexibility and survivability to meet these indefinable future scenarios.

The inescapable fact is that market forces are no longer able to support 'performance at any cost' because defence budgets worldwide are reducing and there is increasing competition for fewer orders.

The key attribute of any future combat aircraft is now AFFORDABILITY, and the technology and design drivers which find their way into new combat aircraft will be those which provide major life cycle cost savings, whilst meeting adequate performance margins.

The processes and mechanisms associated with achievement of major cost savings are discussed as a means of industrial survival in an increasingly competitive and uncertain world.

Key words:
Affordability, Availability, Flexibility, Lethality, Survivability.

1 FOREWORD

1.1 Introduction

The prediction of future threats and the nature of future air combat is becoming increasingly difficult, and is a cause of considerable concern within western aerospace industries. Similar pressures are undoubtedly felt in the rest of the world.

In addition, an increased range of possible solutions is available to customers to address these future threats.

Examples include unmanned aircraft, or stand-off-weapons launched from platforms which do not need to enter combat zones.

It is reasonable to assume that manned combat aircraft will continue to be required in the armouries of the future.

What, therefore, are likely to be the major influences on the design of these aircraft?

1.2 TECHNOLOGY DRIVERS

The evolution of the combat aircraft has been driven in the past by customer demands for dramatic improvements in performance, from generation to generation.

Such step improvements have been supported by large annual defence research budgets, or have emerged in times of national crises as a need-driven expenditure, and have embraced all areas of scientific research and technology development.

The adoption of jet propulsion revolutionized combat aircraft, as did digital computing - both in its applications within the aircraft and perhaps more importantly, in its use in the design processes, from which so many subsequent performance benefits emerged. In the past 20 years, the drive to achieve stealth greatly influenced the shape of combat aircraft and the development of new materials - but at a significant cost.

No doubt, there are still substantial research activities taking place in technologies which might find their way into the combat aircraft of the future. Examples which have had some publicity include:

Gravity management

Directed energy weapons

Gas plasmas.

However, even in a world where there are probably more wars and areas of political tension than at any previous time in history, market forces are no longer there to support 'performance at any cost'.

2 PERCEPTIONS OF THE FUTURE

2.1 Perceptions of Operational Needs

Governments and their armed forces must always be prepared for the unexpected.

The past 10 to 15 years has shown that this is easier said than done.

The western world has seen growth in:

Uncertainty of the threat

Diversity of operational roles

Need for rapid reaction

Pressure on domestic budgets.

Domestic budget reductions and cuts in defence spending are making **affordability** the key driver in finding solutions to all other problems.

A summary of the Customer's **key attributes** for a future combat aircraft are emerging as **Affordability, Lethality, Flexibility, Availability and Survivability (ALFAS)**.

2.2 Industry Perceptions

In general, industry has read and understood the messages.

Worldwide defence expenditure trends are falling and are unlikely to increase in the foreseeable future.

The defence business sector has been responding to this trend over the past 10 years and many of the previously state-owned industries have transferred into commercial ownership, where the major issue has become one of survival.

In a shrinking market the intense competition generated by excess capacity focuses on industrial costs as the major target, with much evidence of downsizing and efficiency improvements.

Some major companies have identified core competences and moved into the part-product defence business as a strategy for survival, while others have exited the business or tried to diversify into defence-related or non-defence products.

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

Another strategy for survival has become apparent recently in the USA, through major defence industry consolidation and the formation of super-group defence companies.

In a competitive world, non-US defence companies have to recognise the enormous buying power of these super-groups and find mechanisms to stay competitive.

In short, industry perceptions of the market change have had a dramatic effect on the shape and nature of defence business and the view of the future.

From a combat aircraft viewpoint, the fundamental impact has been the drive to put Norman Augustine's Cost Curve into reverse. While this may seem to be wishful thinking, achievements to date within the Eurofighter consortium indicate that major cost reductions are achievable - even within ongoing programmes, and additional avenues for cost reduction may open up for future combat aircraft which are not yet at the concept stage.

Affordability is the real challenge for the future of the defence industries.

3 MEETING THE CHALLENGE

3.1 The Future for Design

A balanced solution needs to be found to the Customer's ALFAS criteria for any future combat aircraft. The key attribute, however, from the Customer's viewpoint and from an industrial viewpoint is that of **affordability**, and here, the term 'affordability' covers all aspects of the life cycle costs:

> The non-recurring costs, essentially design and development
>
> The recurring costs, i.e. the unit production costs
>
> The operating costs, i.e. the through-life costs of running the fleet.

Given that there is no 'off-the-shelf' product which might meet the Customer's needs, industry will have to address how major cost reductions are achieved in each of these areas.

This is the key challenge facing industry and the designers of future combat aircraft.

Some of the current and future mechanisms for achieving major cost saving can be identified today.

3.2 Non-Recurring Costs

In the non-recurring costs area, 'time-to-market' is the key. The longer it takes, the more it costs.

Programme compression can be achieved by increasing the levels of **concurrency** across all engineering stages, from concept through to manufacture and test. Increased concurrency, however, can bring increased risk, and concurrency needs to be supported by new, robust, design-to-manufacture processes which allow seamless data transactions across discipline boundaries, with rigorous configuration control. Concurrency also demands a change in workforce culture, from 'discipline-centred' to 'team-centred' ways of working.

Concurrency and process improvements will, however, not be successful on their own. The emerging solution needs to be 'right-first-time', since 'change' and associated rework will push up cost and destroy any benefit gained from concurrent engineering practices. To be successful, 'right-first-time' has to apply throughout the concept-design-manufacture cycle. Customers and designers need to be able to assess the proposed solution throughout the non-recurring phases of the life cycle and agree the continuing 'rightness' of the product. The emergence of synthetic (or virtual) environments is a potential mechanism for achieving this aim.

The key design-driven mechanisms which support cost reductions in the non-recurring phases of the product life cycle are therefore:

> **Synthetic Environments** - supporting 'right-first-time'
>
> **Design-To-Manufacture Processes** - robust, seamless, concurrent.

3.2.1 Synthetic Environments

What is a **synthetic environment** and how does it operate in this context to support a 'right-first-time' approach?

A simple definition is that it is "A computing-based environment which allows risk reduction of defence issues to take place through the interaction of people, models, simulations, and live equipment".

> It allows different players to:
>
> Assess the impact of force structure changes
>
> Assess alternative methods of warfare
>
> Develop doctrine, tactics and mission plans
>
> Rehearse joint missions
>
> Train force commanders and personnel
>
> Develop and assess products, needs and concepts and

above all

> Allow a **concurrent** and **common** view to be taken by customer, user and provider of the performance, behaviour and interactions of a product **at any stage of its life cycle**.

Customer and industry needs for future combat aircraft have already been stated. Within the United Kingdom a definition of a **synthetic environment** is emerging which addresses these differing needs.

The common picture which is emerging is that of a multi-layer environment, where the top layers are 'operational layers' and are owned and developed by the Customer.

The bottom layers are effectively 'product engineering layers' and are owned and developed by the providers of products.

Models of 'products' (or real products) can be plugged into the 'war gaming layer' of the synthetic environment, allowing cost and performance analyses to be undertaken.

At the very early stages of a new product life cycle, where customer and user needs are not well defined, where the embryo concept solutions are emerging from industry, and at a time when the eventual implementation technologies are not even selected, a simple, parametric model of the product can be introduced into the 'war gaming play-space'.

This can be assessed in conjunction with existing assets, tactics, doctrine and threats in a fully dynamic environment. New tactics and doctrine can be formulated. 'What if' threats can be introduced.

The strengths and weaknesses of the Customer requirement and the industrial solution can be addressed and amended with a common understanding of the rationale for change, the impactof change, and the cost of change.

From the industrial viewpoint, not only can 'virtual solutions' be tested, but also 'virtual manufacturing' and 'factories of the future' can be assessed and optimised.

As the design and engineering progresses, the simple parametric model of the product will expand and develop, becoming populated with more detailed internal models of sensors, weapons and systems, which in turn can be replaced by real equipments.

The growing perception is that the detailed mathematical/ performance models of the whole product and its component systems are themselves the dynamic specifications against which the product and its internal equipments will be procured and ultimately verified and validated.

The 'rightness' of the solution will have been visible to all parties - customer, user, prime contractor and suppliers - from the start of the product life cycle.

3.2.2 Design-To-Manufacture Processes

While **synthetic environments** provide the mechanism for continuous evaluation of the 'rightness' of the requirement and the solution, with relative costs and effectiveness measures of alternatives or changes, the products still need to be designed, engineered, and manufactured, and rigorous and robust processes need to be established which support significant timescale compression in these areas without increased risk.

Concurrent engineering is a business strategy to re-organise people into integrated, multi-function project teams, utilising computer-aided engineering tools as the enabling technology. The main objective is to reduce timescales and improve quality by moving from a sequential series of operations to a more product-focused environment which allows simultaneous activities to be properly coordinated.

Concurrent engineering principles apply to all aspects of a complex weapon system, from concept through to manufacture (and in-service support) and include the airframe, systems and software components of the product.

Taking the airframe design-to-manufacture concurrent engineering processes as an example, concept designs are developed in an integrated product team environment, using computer-aided tools for basic product sizing and configuration, leading to a complete surface definition of the aircraft baseline standard.

All engineering disciplines can be involved simultaneously in this activity, since there is only one 'Digital Master Product Model'. This is accessible to all parties and supports efficient data management, configuration control and management of essential change.

The idealised aircraft concept (which, as a performance model, can also be plugged-in to a synthetic environment) can then be progressed through to a final design.

The electronically-stored 3-D design can be optimised for aerodynamics, stress and electromagnetics, through interrogation by Computational Fluid Dynamic (CFD), Finite Element Analysis (FEA) and Computational Electromagnetic (CEM) codes.

Mass and cost estimates of what at this stage is still a 'virtual aircraft' can be generated from solid-modelling extensions of the 3-D design model linked to existing materials and cost databases.

Users can evaluate the product from a maintenance viewpoint by looking at 3-D representations of access or component installation, and can interface dynamically with the 3-D design either through a computer screen or by partial or total-immersion virtual reality systems. Aircrews can evaluate virtual cockpit layouts in the same way, and the virtual cockpit displays and controls can, in turn, be interactively linked to conceptual designs (models) of systems, at a similar stage of definition.

Production engineering and manufacturing engineering can interrogate the 3-D model and establish jig philosophies (and jig designs), extract surface tooling data for composite skins and establish virtual 'factory-of-the-future' models to evaluate and cost alternative build and assembly philosophies.

All this can be achieved concurrently from the very earliest phases of a product life cycle, long before major costs are incurred. The commitment to detailed design and manufacture of parts can involve all disciplines, and the impact of design change can be costed and agreed by all.

The benefits of concurrent engineering, integrated product teams, and electronically-based, common design-to-manufacture tools and processes are:

- Compressed timescales
- Increased productivity
- Increased quality - fewer unplanned design changes
- Improved design visibility
- Rapid option evaluation
- Carry-through of products into training and support

and above all

- Control, visibility, and major reduction of cost.

3.3 Recurring Costs

Recurring costs are those associated with manufacturing the product. The costs of making an aircraft, i.e. the Unit Production Costs (UPC) are made up of two parts:

a) The **organisational and labour** costs -

- How many people does it take?
- How long does it take?
- How are they organised to do the job?

b) The **bought-out** items -

- Materials, tools, equipment.
- Cost-reduction mechanisms need, therefore, to operate in both areas to be fully effective.

The 'in-house' costs can be addressed from the beginning of the product life cycle, given that production engineers have full visibility and involvement in the design-to-manufacture processes. The ability exists now to model 'virtual factories' to visualise and cost:

- Alternative build philosophies
- Alternative assembly and equipping philosophies

Process flow control concepts

Cellular manufacture concepts.

The workforce can learn new skills and be involved in the virtual manufacturing process. Ultimately, multi-skilling leads to more flexibility and easier load scheduling on the shop floor.Material cost reduction can be addressed in a number of key areas.

These include:

Reduced Stock holding. Don't buy material up-front which will not be used immediately.

In 'consumable' areas, such as fasteners, get supplier buy-in to 'direct-line-feed' concepts, where they have responsibility for ensuring that there are just enough components available at any time to support manufacture/build.

Since equipment makes up such a large percentage of the cost of the aircraft, again get supplier buy-in to **just-in-time** delivery to the appropriate point in the build-line.

In this instance two factors are critical to success:

Guaranteed scheduled adherence

Guaranteed reliability.

Earlier, Augustine's Cost Curve was reversed, and on Eurofighter that is exactly what has been achieved. To effect this dramatic saving, a 50% reduction in make-span has been necessary, reducing build cycles from 36 months to 18 months. This compression is being achieved in all stages of build and further savings may be possible in the life of the aircraft. This provides a benchmark for combat aircraft 'factories of the future'.

It needs to be re-stated that over 70% of the UPC is made up of equipment costs. The efforts put in by the prime contractor to reduce airframe manufacture costs need to be matched equally by equipment suppliers so that uniform cost reduction can be realised in the delivered product.

3.4 Operating Costs

The potential savings during the service life of the fleet might be in excess of 25 to 35 years.

Operating costs are a major part of the defence budgets and cost reductions are possible in several areas.

Training costs can be reduced in a number of ways.

An obvious mechanism is to reduce aircrew members to a minimum. Can missions previously performed by two-crew aircraft be performed equally well by a single-crew solution? This needs to be addressed by customer, user, and provider, and design solutions validated and accepted from the concept stage onward.

Flying training is expensive. Can more ground-based training be substituted by improving the quality and capability of simulator and war gaming training - drawing on the products of synthetic environments and engineering models?

Consumables costs are largely linked to flying hours.

Options in this area are reductions in flying hours (linked to training costs) and efficiency gains in engine technology and fuel consumption.

Maintenance and reliability costs are major areas for savings.

Data from 1970 to date shows that the trend in whole-aircraft reliability is moving in the rght direction, but there is still a long way to go.

If we look at improving whole-aircraft reliability by reducing existing arising rates by 50% we can achieve almost 20% savings in operating and support costs. Less maintenance (scheduled and unscheduled) also means fewer maintainers and again reduced training costs.

Engine contributions may appear high, but although engine removals are already few in number, they are high-value items. Perhaps a solution here, is for military operators to look at their civil counterparts and consider buying 'power-by-the-hour', with improved guarantees of engine reliability.

The drive to improve reliability and reduce maintenance and spares costs really is an area where designers and engineers, particularly in the equipment supplier companies, can have a major influence on **affordability** of the future combat aircraft.

3.5 Summary

I have proposed some mechanisms which look at major ways of tackling cost reduction across all phases of the product life cycle.

Synthetic environments can help by providing a better definition and understanding of requirements and solutions to all parties from the outset of the programme.

Concurrent processes and **lean manufacture** take time out of the programme and thereby reduce cost.

Reliability improvements take cost out of Fleet Operation.

4 CONCLUSIONS

This paper has concentrated largely on **affordability** issues and cost reduction mechanisms for the next generation of aircraft.

In particular:

There is a global long-term decline in defence budgets

These are lean times for industry and survival is paramount

Cost reduction and value-for-money are the key words for success

Low-risk solutions are being looked at by customers and industry

Evolution, not revolution is required at this time.

Research and development will continue at reduced levels and new technologies will find their way onto future combat aircraft, but they will have to demonstrate major cost benefits and earn their place on the aircraft.

The major focus now needs to be directed towards affordable solutions and, therefore, this has to be regarded as a very fertile time for **innovation**.

AGILE MANUFACTURING - MYTHOLOGY OR METHODOLOGY ?

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SUMMARY

The 'lean manufacturing' concept is well known and its application through the use of principles such as Pareto analysis, Kanban, JIT and WIP (etc) has the potential to realise significant cost benefits. There is, however, a potential down side to the 'lean and mean' environment; a reduced ability to respond to change. The need for a level of flexibility in the overall manufacturing process has therefore been recognised.

Flexibility can be planned into the process at an early stage, perhaps as an intrinsic part of a risk management exercise for example, but such processes tend to be flexible only within the pre-set boundaries. In practice, however, the operational environment may be subject to a wide range of intrinsic and extrinsic variability which cannot be accounted for during the planning stage.

More recently a new concept has begun to emerge which seeks to address the above issue; Agile Manufacture. The concept remains somewhat vaguely specified at present and has been variously interpreted as synonymous with 'flexibility', 'responsiveness' and even 'lean'. Alternatively Agile Manufacture may be seen as a new approach to production which encompasses flexible engineering methods and operations management. This paper addresses the agile concept from a manufacturing viewpoint and seeks to understand if agility is in fact a 'paradigm' or merely new coinage for an old currency.

BACKGROUND

The quest for improved manufacturing performance is driven by customer requirements and survival in the competitive market environment. The early craft based industries were characterised by manual skills and low production rates and high levels of intrinsic variability which could be harnessed as flexibility. Early craft products were often commissioned to meet individual customer requirements but the attendant low production rates and high variability could not meet the mass market demands created by the post industrial revolution prosperity.

Mass production created a new vision of efficiency based on high volume throughputs, minimum change and more consistent (though not necessarily better) quality. The need to evolve and maintain a competitive edge has subsequently driven the manufacturing processes through lean manufacture to flexibility. Concurrently the demand for a 'total quality management' (TQM) approach has been prompted by an increasingly discerning customer. We must now consider the new drivers for the next generation of airframes and develop a view on the way forward.

In the context of the military aerospace airframe industry the new drivers for change may be summarised as: Affordability (as evidenced by the Augustine exponential), Performance (mass) and Low Observability. This is in marked contrast with the previous, almost exclusively, mass dominated requirements. The solutions require a more holistic approach to process optimisation and potentially go beyond lean and flexible practices. The 'agile manufacturing' paradigm has been offered by some authors as the way forward but as reported by the OSTEMS Agility mission to the U.S.A. " We found that while there is yet to emerge a comprehensive and definitive definition of Agility, real and concrete initiatives, research and practice are sprouting throughout the country" (Ref.1). This apparent lack of definition for the agile concept is understandable as the various current views generally appear to group a

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AUTHOR	DATE	KEY ATTRIBUTE
Twigg et al	1992	New product integration; Delivery; Quality
Crowe	1992	Flexibility
Draaijer	1992	Flexibility; Quality; Costs; international competitiveness
Lee	1993	Responsiveness
Japikse et al	1993	JIT; lean manufacture; virtual enterprise
Vastag et al	1994	Flexibility; JIT; time to market; global competitiveness; Quality; Integration
Kaighobadi et al	1994	Quality; Cost reduction
Pant et al	1994	Integration; Responsiveness; Adaptiveness
Ross	1994	Flexibility; IPD; Strategic partnerships
Noaker	1994	Strategic partnerships; core competecies; empowered teams
O'Conner	1994	Flexibile manufacturing systems
Gehani	1995	Flexibility; Responsiveness; New product introduction; Integration
Beaty	1996	Flexibility; Responsiveness; build to order

TABLE 1 - AGILE PROCESS ATTRIBUTES

number of ideas and practices, many of which are well known, under the 'agile' heading.

This paper therefore considers if the 'Agile Manufacturing' concept offers a new approach, within the context of military aerospace, or is it merely new packaging for existing concepts. In addition the subject of the technology requirements for an agile environment are considered and a view given on whether agile processes can be considered independently of the technology base.

AGILE MANUFACTURE

The term 'agile' manufacture is frequently taken to be synonymous with 'lean', flexible' and 'robust' processes and there is no current single definition which allows 'agile' to be characterised as an independent concept. The reason for the current confusion is understandable. The term 'Agile Manufacture' was originally coined by a team of researchers at Lehigh University in 1991 to describe a more holistic approach to the requirements for global competitiveness. Since then a number of papers have addressed the issues and although some common themes emerge the views are far from consistent. Table 1 summarises the key themes from a number of papers published over the past decade.

The most common theme which emerges is flexibility with responsiveness, integration and quality also highlighted and even the quite independent 'lean manufacture' makes an appearance. However none of these, and in particular flexible manufacturing, are new concepts. If 'agility' is an independent concept then we need to clarify the differences between 'lean', 'flexible' and 'agile' processes, if indeed they exist.

In order to understand these potential differences a simple model will prove useful. Figure 1 proposes a model based upon two sets of characteristics:

Si represents a set of specifiable variables (i) associated with a product (or range of products) .

Cj represents a set of corresponding variables (j) associated with the process.

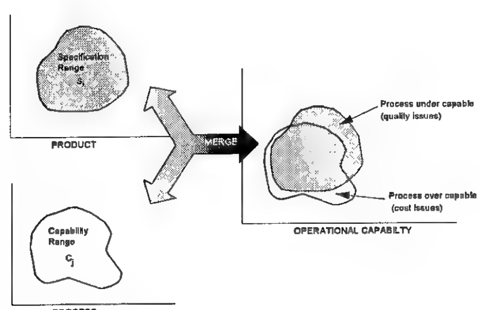


Figure 1 - Operational Capability Model

So, for example, Sn may define a tolerance band for a particular product dimension and the corresponding Cn the process capability with reference to that particular variable.

Values of i and j cover all characteristics of the product 'specification' and process capability

including quality, rates, materials, processes, etc. Taking the complete specification range for the product(s) and process(es) therefore produces a set bounded by the product specification range and the process capability range respectively. Superposition of these two sets then allows a direct comparison between the product and process and therefore a definition of Operational Performance.

Three conditions are evident from figure 1:

a) Si > Cj for which the process in incapable of delivering the required product specification therefore giving rise to problems with quality. Quality is considered as TQM in this context as the specification range covers more than geometry's, defects, etc.

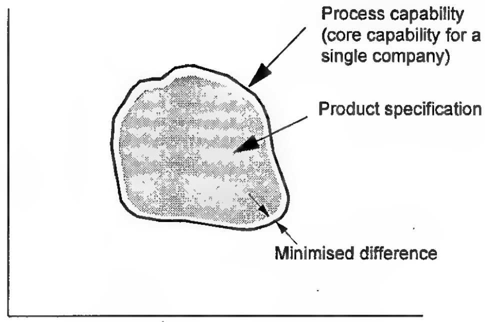
b) Si < Cj for which the process has a greater intrinsic capability than that required to meet the product specification. This then represents an overcapacity which in turn may be evident as 'work in progress' (WIP), machine idle time, overhead charge, etc. Alternatively this condition may be seen as an opportunity for flexibility but processes operating in this condition are over-expensive and generally non-competitive.

c) Si = Cj for which the process capability and product specification are a perfect match. This condition is met only at the two points where the set boundaries cross on figure 1.

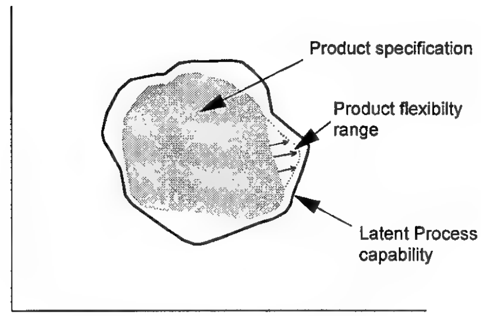
This model may now be developed, as indicated on Figures 2 and 3, to define lean, flexible and agile manufacturing as follows:

If Si ~ Cj within a relatively close margin then the operational performance may be defined as lean. This condition is however highly unstable as relatively minor increases to the product specification will cause the Si > Cj condition discussed above. The lean process will however deliver the product at minimum operational cost but the price paid is an inherent inflexibility. In order to deliver a lean process it is necessary to optimise the operation in terms of quality and logistics, etc. These may then be deleted from the list of key attributes for agility given at table 1as they are now seen to be aspects of a lean process.

The problem outlined above was realised as processes were moved towards greater levels of leanness. The solution was to anticipate a level of change and provide sufficient capability in the appropriate areas. This would be represented on



A) LEAN OPERATIONAL CAPABILITY



B) FLEXIBLE OPERATIONAL CAPABILITY

Figure 2 - 'Lean' and 'Flexible' models

the model as deliberately creating the condition Si < Cj for a selected range of i,j. This then provides flexibility within the anticipated range of variability but at the costs associated with the Si < Cj condition.

Flexibility and responsiveness are intrinsically related as a flexible process which cannot respond in timely fashion as required is of little value. Again we can delete those key attributes associated with flexible manufacturing from table 1.

By the above process the main themes identified from table 1 have now been subsumed within lean and flexible processes, leaving only a number of loosely related topics associated specificaly with the agile concept. The initial conclusion may therefore be that 'agile manufacture' is not an independent paradigm. However, the proposed model may be extended as shwn on Figure 3 to examine a further possible approach and one which is becoming more important as we move towards the new business environment. This new environment is driven by a greater customer demand for products built to his requirements rather than off-the-shelf purchases. Or as stated by Beaty

"The philosophy has changed from build-to-plan to the infinitely more complex build-to-order" (Ref.2).

We must not feel complacent in the airframe business because we invariably build to specific customer requirements. Our products are often multinational and/or multifunctional and configured to meet a compromise between the various customer requirements. Additionally the production span of a typical airframe is many years (e.g. 20 in the case of Tornado) and the customer(s) may reasonably expect the product to be updated in line with best SOA technology on a regular or even continuous basis. Foreign sales may also be dependent on tailoring to meet the requirements of customers with a world of suppliers to choose from and special needs driven by local circumstances. Neither the lean nor flexible processes can accommodate changes on this scale or with the level of unknowns associated with such an environment. The build-to-order environment requires capability beyond flexibility.

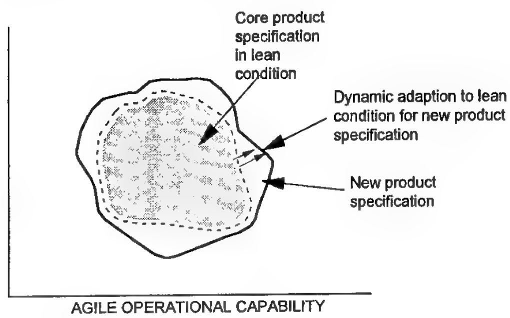


Figure 3 - 'Agile' model

The lean process requires advanced and fixed definition of the product specification in order to be optimised, the flexible process requires an anticipated and limited level of change but the new environment described above demands an ability to respond to unanticipated change. In terms of the model the Si ~ Cj condition (i.e. lean) is dynamically reconfigured such that any change in Si is immediately reflected in a corresponding change in Cj maintaining a lean operating condition. Such a process may be fairly described as 'agile', or as defined by Noaker: as " Agile - The measure of a manufacturers ability to react fast to sudden unpredictable change in customer demand" (Ref 3). It is an important distinction that this dynamically lean environment does not carry the overheads associated with the planned over-capacity of a flexible process.

Such a process would be characterised by elements of best practice offered by the lean manufacturing approach. It is therefore assumed that supply chain management, total quality management (TQM), statistical process control (SPC), Pareto analysis, etc. are embodied within the baseline business processes and core competencies. The agile environment will, however, require additional attributes and in particular:

1) Vision. This requires the development of a comprehensive long term strategy based upon an objective analysis of current position and a clear corporate vision of the future business direction. Benchmarking of core capabilities and in particular the identification of strengths and weaknesses is a necessary part of the envisioning process in order to establish the current level of competence and capacity. It is then necessary to provide a predictive modelling capability which enables the impact of the various future business scenarios to be translated in terms risk (ie business case), technology requirements, capacity planning, capital investment, etc. This then provides a sound basis for the identification of the necessary core competencies, strategic investments and long term partnership plans.

2) Strategic Partnerships It is anticipated that, typically, an individual company will not be able to invest sufficiently in the complete range of risk reduction activities to provide the required strategic position for each future anticipated. It is likely, however, that a number of companies may perceive the same opportunities and share the common funding, facility and/or resource problems. A recognised solution requires the formation of a 'virtual enterprise' or Keiretsu which is characterised by a high level of co-operation at both corporate and operational levels as distinct from the normal customer/supplier relationship. The advantages offered by this approach are a significant broadening of the resource, skills, experience and facility base without any need for major investment from any individual member. Risks are not only shared but may be targeted at the 'least risk' partner such that, for example, a niche technology may be developed by a Keiretsu member with other outlets for exploitation. Overall risk levels are therefore minimised.

The Kieretsu may be expressed using the previous modelling approach as shown on Figure 4. In this example the core company 'A' has

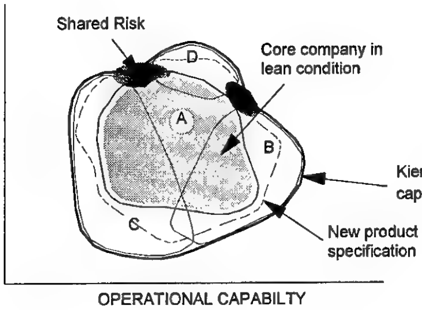


Figure 4 - Kieretsu model

formed a Keretsu with companies 'B', 'C' and 'D' to cover the majority of the new product specification but two small regions remain out of specification. This deficit may be remedied by a shared risk investment or by an individual company extending its own core capability. It is clearly important to identify these deficiencies during the formation of the Kieretsu in order that appropriate action may be taken prior to implementation. Sharing of core benchmark data is a method of achieving this requirement.

3) Operational Optimisation. The improvements in operational efficiency which arise from volume throughput provide a powerful argument for growth and aggressive capture of maximum market share. This may appear to contradict the principal of Kieretsu in which shared risk must be rewarded by shared access to the market. The key to developing the correct approach lies in the operations model shown as Figure 5. The unit cost typically reduces with increased throughput due to amortisation of non-recurring engineering activities and set-up times, etc. over a larger volume of units. This view is valid for simple repeats of the basic unit and is common in many mass production industries. In the airframe business, however, increased throughput is often at the expense of increased variety. Variety has the effect of increasing levels of non-recurring change, tooling inventory and maintenance, complexity in set-up, lead times, etc. and therefore to increase the unit cost by increasing the man hour content and overheads. Variety is therefore a problem for technology rather than capacity and low cost at low volume technologies are essentially those which minimise these effects . If increased throughput is achieved only at the introduction of increased variety then the cumulative effect will generally display a minimum range as shown on Figure 5. Therefore the optimum operation may be at a throughput level considerably less than that required to execute the newly expanded business.

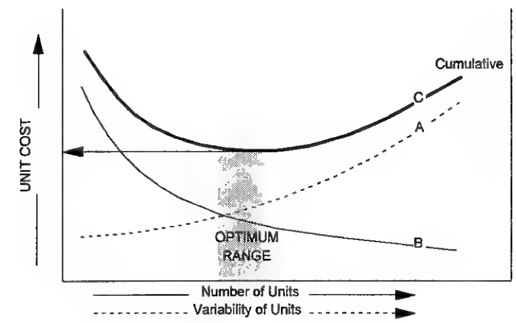


Figure 5 - Operational Performance

An agile technology may be considered as one which can accommodate higher levels of variety with less impact on unit costs. The cost of variety curve 'A' on Figure 5 is therefore reduced and the effect is to move the optimum range to the right thus allowing higher throughputs at less unit cost. The two means of achieving this condition are:

a) Investment in core technology (ie single company solution)

b) Formation of an appropriate Kieretsu.

The best option will depend upon the balance between core investment and return for each scenario.

4) Integrated Engineering (IE). The concurrent engineering environment will be extended at both the requirements capture phase to include customer representation and at the implementation phase to include the key suppliers and Kieretsu members. The IE teams will require a toolset which at a minimum must contain a process modelling capability, common Digital Product Definition (DPD) database and an integrated information technology system. This is particularly necessary when the Kieretsu partners are geographically remote. Process modelling is required to develop the various 'what if' scenarios associated with the risks and opportunities and translate these into potential divisions of responsibility and workload.

5) Agile technologies. Whilst much has been written on the operational aspects of Agile Manufacture very little is evident in the area of supporting technology. The development of a lean operation is not critically dependent on

technology as the key factors are more concerned with the 'soft' issues of infrastructure, inventory, logistics, etc. against a background of an existing core technical capability. Similarly a flexible operation does not necessarily require a new approach to technology as it is primarily achieved by a planned over-capability using the existing technology base or by exploiting 'latent potential' ie technologies that can do more than currently required, usually at the expense of over-specification. The agile environment of dynamically lean, as discussed above, cannot be considered independently from the underpinning technologies. This is because lean can only be defined by an operational optimisation within a given technology base (as discussed in 3) above). Agile is therefore distinct from lean and flexible in that it requires a new approach to technology. In effect by adjusting the cost of variety curve (A) on Figure 5 through the application of 'agile technologies' the optimum range (ie lean condition) may be adjusted to give maximum operational performance.

It is therefore suggested that the concept of an 'agile technology' is fundamental to the development of agile manufacture. This requirement generally appears to have been neglected in the literature to date, probably because most authors have considered agility as an extension of flexibility rather than as a dynamic form of leanness. The importance of technology to agile manufacture is therefore considered in more detail the final section to this paper.

AGILE TECHNOLOGIES

The traditional driver has been Performance (mass) and the response has been to apply new materials technology. The industry has therefore seen a marked shift in the balance between structural materials over the past few decades. In particular a growth in the use of Advanced Composites, largely at the expense of Aluminium, and a shift from wrought Titanium product to Superplastically formed (SPF) and Diffusion Bonded (DB) structures. However, no fundamentally new materials are on the horizon and future success will depend on the ability to use what we currently have in a smarter way. This discussion will focus on key new metallic and composite technologies as these are likely to be dominant on future airframes. Tooling both for parts and assembly will also be considered as they often represent major sources of inertia within the process, due to the high capital investment and long lead times, and are therefore significant obstructions to agility.

The time consumed by the non-recuring activities such as planning, tool design and manufacture, etc. are major inhibitors to agility. These effects become increasingly significant as we move towards a low volume, high rate of change, environment. This effect has been recognised for some time in the R&D environment and has lead to the development of rapid prototyping technology. The automotive sector has been particularly active in this area and has developed techniques for 'turning round' prototypes in days or even hours, depending on the complexity of the product. In order to achieve agility a similar approach needs to be taken to the production environment. This would seek to reduce the lead time for non-recurring activities to a level compatible with small batch production. In this way the currently clear distinction between non-recurring and recurring activities would, in effect, cease to exist.

One theme which runs through all the approaches discussed is the greater use of the DPD. The digital database consists of feature based drawing definition on a generally accessible design platform such as 'CATIA' which may be used to drive, via intermediate software packages, process analysis and machine operation. The DPD is fully inclusive of design, materials and quality requirements and from this database, together with inputs from the appropriate Projects, automated planning and process optimisations may be derived. Agility derives primarily from the potentially rapid response within manufacture to changes to the DPD but these changes may be read directly into the subsequent stages of processing only if appropriately responsive technologies are available. An important technology which has much too offer the agile manufacturing approach is LASER processing. Because LASERS have multiple uses and are easily driven from the DPD they provide a versatile and flexible alternative to certain processing options. These are highlighted in the discussion below.

The following discussion does not comprise a fully comprehensive list of all potential agile technologies but is intended only to provide an illustration of the types of processes and approaches which are key to achieving agility.

1) Agile composites details. Generally the main throughput of high performance airframe

composites production is through pre-preg and autoclave based processing route.. This has had

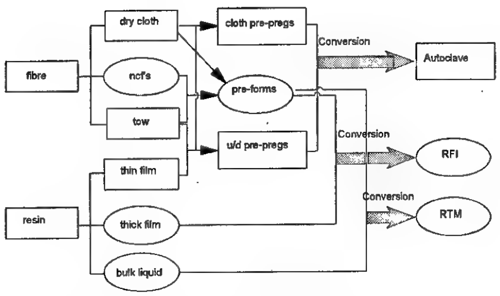


Figure 6 - Agile Composite Materials

considerable success over the last two decades but as the need for greater levels of composite are required in order to meet the new drivers the relative inflexibility of this approach becomes more apparent. The key to the agile approach is to provide sufficient flexibility to allow the process to be matched to the part requirement rather than driving the part through a single non-optimum process option. Figure 6 illustrates the principal.

The base fibre and matrix resin systems are offered in a greater range of forms. The fibres are processed as advanced fabric materials such as the non-crimped fabrics (ncf's) which allow the subsequent production of high drape, high performance, pre-forms. The pre-form may contain features such as pre-layed stiffeners and local reinforcements using the type of technology investigated by Brunel University (Ref.4). This programme examined the use of advanced robotics and visual imaging systems to cut, pick and place the highly conformable ncf's and to form and place stiffener details by automatic guidance. Such a process could be driven by the DPD and as hard tooling is not required at any stage in the pre-form manufacture it is therefore highly agile. Furthermore the highly drapable preforms can be easily and quickly formed to complex shapes reducing significantly the number of operations and skills otherwise required by the pre-preg route.

In parallel the matrix resin is presented in one of three forms:

a) the conventional thin films for the pre-pregging process

b) as thick film for Resin Film Infusion (RFI)

c) bulk liquid resin for Resin Transfer Moulding (RTM).

These then form the 'conversion' options by which the basic material is processed to become fully functional composite. RTM and RFI do not detract from the forming advantages of the pre-forms as the resin is not introduced until after the forming process is complete. The one-shot forming of pre-forms also eliminates the need for hot debulking operations and any associated hard tooling. A number of 'mix and match' options for the fibre and resin forms are therefore available which complement the existing pre-preg routes. It is in consequence possible to optimise the match between part and process over a much greater range of products and the process is therefore inherently agile.

A key inhibitor to the introduction of agility is the current dependency on hard tooling. This is often seen almost exclusively as the mould tools but it should be noted that these only form a small part of the overall tooling requirement for parts production. The high inventory , cost and lead time associated with the complete set of tools for even a simple part is a major barrier to change and hence a limiting factor for agility. Tooling must be therefore considered under a number of separate headings:

a) Cutting templates. Used to provide the shape of individual plies or stacks of plies. These may be replaced by the use of automated cutting technology such as ultrasonic knife or water jet profiling. These methods are easily driven from the DPD and offer the further advantage that materials wastage may be minimised by the use of ply nesting software.

b) Positioning templates. Used for the manual positioning of individual plies, stacks or other details to be included in the layup. These templates can be replaced by the use of Optical LASER Templating (OLT) which projects an accurate visible line, and other useful information such as ply orientation and operation number, directly from the DPD, onto the working surface of the layup. The projected line is accurate enough to replace templates for general layup and hand machining operations and may also be used to reveal the location of otherwise hidden detail buried within the laminate. OLT may also be used in conjunction with special transducers fitted to the mould tools to provide very accurate tool location for automated handling processes.

c) Pre-forming tools. These are used for debulking and pre-forming operations when producing complex pre-preg layups. They may be eliminated by the use of the advanced fabric technologies as discussed earlier.

d) Mould tools. The general approach to improved agility is to minimise cost and lead times This is only feasible if component quality is not affected otherwise there could be serious effects on the efficiency of subsequent operations. A typical agile approach for a small part, for example an access panel or door, would be as follows: A low cost master tool is produced, in reverse geometry, directly from the DPD using Stereolithography and incorporating the appropriate off-sets and features required. A tool is then taken directly from the master using a low temperature curing pre-preg.

High rate processes such as RTM offer the further advantage of reducing the need for 'rate tooling' and hence the tooling inventory and maintenance costs.

e) Check templates. Used to provide confirmation of part geometry. This can be replaced by LASER digitising the component surface using, for example, the SMART system. This digitised surface data may then be compared directly with the DPD in order to check accuracy and also to provide geometric data for subsequent machining and assembly operations.

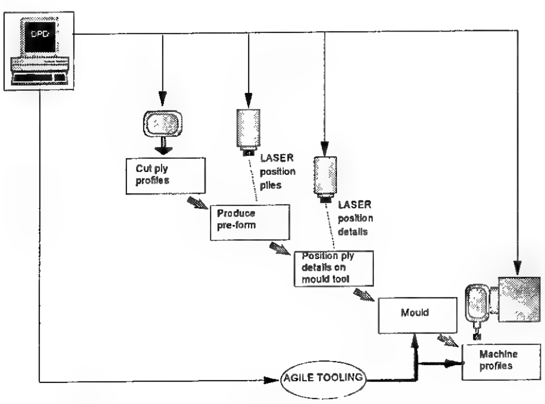


Figure 7 - Agile Composites Process

f) Machining fixtures. For routing operation flexible fixturing may be used such as that developed by Cincinnati which uses individually adjustable hydraulic rams, fitted with appropriate effector heads and arranged in a rectilinier array, to conform to each individual part geometry. The ram positions are driven by the DPD and may be reconfigured in a matter of minutes from part to part. Drilling operations are considered under item 3) 'agile assembly ' discussed below.

Figure 7 summarises the key elements of the process.

2) Agile metallics details. The use of Diffusion Bonding (DB) of titanium alloys and Superplastic Forming (SPF) of aluminium and titanium alloys has been established aerospace technology for a number of years. The basic process for DB/SPF is, in part, inherently agile but similar to composites the limitation to full agility is seen to be the use of fixed mould tooling for the SPF cycle. The basic DB/SPF process is as follows:

a) Sheet metal detail preparation. The final form of the details are determined by the thickness profiles of the starting sheets and DB pattern. The 'flat pack' sheet profiles may be LASER cut and if necessary n/c machined to the required profiles or alternatively the 'flat pack' may be constructed from individual LASER profiled sheets. Both LASER cutting and n/c machining are controlled directly by the DPD.

a) Silk screen print stop-off pattern. The stop-off pattern is applied using LASER etched silk screens with the pattern again determined directly from the DPD. Silk screens are cheap and easy to produce. DPD driven LASER processing may also be used to edge weld the flat pack to provide the necessary air tight seal for DB.

b) Diffusion bond. The DB process is not specifically tooling critical and therefore the process is highly agile in that any change to the DPD can be rapidly converted to the new sheet profile, stop-off patterns and DB'd assembly pack.

c) Superplastically Form. The requirements for hard mould tooling for the SPF expansion process is analogous to that discussed above for composites moulding and similar approaches may be considered. A low cost master tool is produced, in reverse geometry, directly from the DPD using techniques similar to those described for composites. A tool, suitable for use at high temperature, is then taken directly from the master using a castable ceramic. Alternatively a cavity tool may be cut directly from the DPD in graphite. In either case a generic containment tool is required in order to act as a pressure vessel. The high rate 'Hot open die' process offers the further advantage of reducing the need

for 'rate tooling' and hence reducing the tooling inventory and maintenance costs

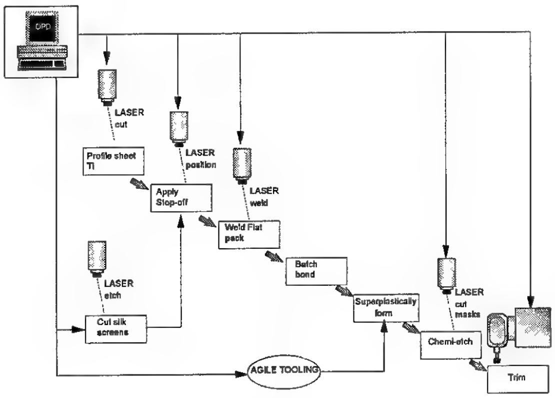


Figure 8 - Agile Metallics Process

d) Chemi-etch. LASER positioning of the part and cutting the protective maskant or alternatively manual cutting assisted by OLT are highly agile processes driven directly by the DPD.

d) Machine to finish. Similar to those described for composites.

Figure 8 summarises the process.

3) Agile assembly. Restrictions on assembly agility are similar to those discussed above for details. Primarily the problem lies in the conventional approach with the need for expensive and rigid tooling to position the details and facilitate machining operations such as drilling. Even minor change such as the relocation of a fastener can have serious implications on the tooling. The key processes for agility have been generally discussed above. Taking the example of a centre fuselage section a general agile process may be as follows:

a) Geometric modelling. Variation Simulation Analysis (VSA) is used to model and define the assembly process. This can be used in conjunction with the component digitised surface geometry to compare directly with the DPD database in order to check accuracy and identify potential fit problems off-line.

b) Component location. Uses simple location jigs which interface with features accurately machined or moulded into the details. Key self locating features are built into the parts, for example 'golden holes' and these are used to locate the parts during assembly. The SMART LASER system also provides a DPD driven highly accurate datuming of jigs and check on the location of parts. Control of the critical interfaces uses Tolerance Variance Management (TVM) to provide the necessary high tolerances only were necessary and this is part of the DPD. As these features are built into the agile details, and derive directly from the DPD, they also impart agility to the assembly process.

c) Drilling and fastening operations. For semi-finished 'direct line feed' components the drilling and localised machining operations use automated machine tool systems which utilise generic 'picture frame' type fixtures each suitable for a wide range of components. A typical system comprises LASER location of fixture and part and reference to the digitised surface data to allow accurate positioning of the effector head irrespective of variations in surface geometry and position. For the 'fit on assembly' option a similar system is used but with datums taken principally from the location features on the components and a minimum number on the assembly jig.

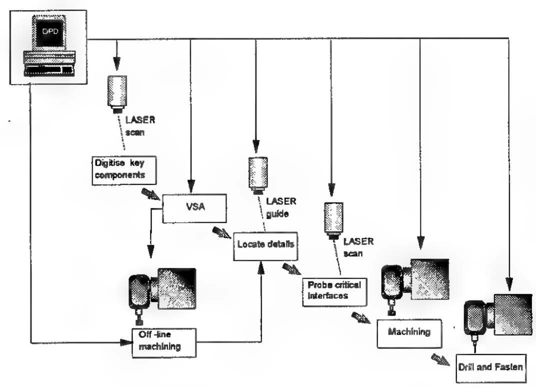


Figure 9 - Agile Assembly Process

Figure 9 summarises the key elements of the process. Agility derives form the transfer of datums from jigs and fixtures to the details which are controlled directly by the DPD as discussed above. All datums are therefore directly related to the DPD and therefore to each separate component and any required changes can be quickly reflected through the detail manufacture and planned through the VSA and TVM modelling processes.

CONCLUSIONS

A model has been suggested in which 'agility' emerges as a distinct concept from 'lean' and 'flexible' manufacturing processes and which may be summarised as 'dynamically lean'. A number of attributes are identified which provide pointers to an agile approach. It has been suggested that the agility concept will in practice be critically dependent on a technology base that minimises the traditional distinction between non-recurring and recurring activities and allows a closer match between process and product requirements.

Although agility is conceptually distinct the enablers are either in place or in development and agility lies within the grasp of those with the skills to identify and develop the key enabling technologies and integrate these within the optimum business environment.

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La maîtrise des coûts dans le développement des systèmes et de leurs logiciels

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1. SOMMAIRE

Etant à la fois Systémier et Missilier, AEROSPATIALE MISSILES traite de Systèmes incluant une forte proportion de logiciels. Selon le type de produit (Systèmes Intégrés de Commandement, Installations de tir , Missiles, Equipements...) la part du logiciel est plus ou moins importante par rapport à celle du matériel.

La définition d'un Système résulte d'études qui ont permis d'identifier et caractériser les fonctions et les architectures (solutions techniques). Ces solutions techniques, sont le résultat de choix technologiques pouvant résulter d'un arbitrage entre le tout logiciel, le tout matériel, ou des solutions mixtes intermédiaires. Le coût prévisionnel des logiciels est fortement dépendant des choix effectués et ne peut donc être indépendant de celui du reste du Système.

Ainsi, pour AEROSPATIALE MISSILES, la maîtrise des coûts des logiciels embarqués ne peut se concevoir que dans le cadre d'une maîtrise des coûts de tout le Système à réaliser. C'est la raison pour laquelle nous décrivons la démarche mise en oeuvre dans les phases amont (Faisabilité, Définition) pour réduire les coûts de développement du Système.

2. PRINCIPALES DIFFICULTES CONCERNANT LA MAITRISE DES COUTS DES LOGICIELS

Le développement d'un Système d'Armes performant et novateur, implique souvent un pari technologique, sur la composante "Missile" notamment. Pour faire face aux difficultés rencontrées pendant la phase de développement, on peut être amené à demander au système de traitement de l'information, jugé - peut être à tort - plus facile à modifier, de résoudre une partie des problèmes liés au pari technologique. En fonction des risques pris, on aura donc été amené, notamment pour l'informatique embarquée, à prévoir des architectures de calculateurs offrant de grosses puissances de calcul, dans un petit volume. Les choix technologiques qui en découlent amènent alors à choisir des composants électroniques nouveaux et coûteux pour lesquels le choix du langage de programmation est souvent très réduit, voire imposé par le fabricant.

Dans le contexte économique actuel, les contraintes de coût et de délai peuvent conduire à un chevauchement important entre les phases de définition et de développement, afin de réduire la durée du cycle de développement des systèmes. Dans les démarches classiques il est préconisé, par exemple, d'étudier d'abord les tâches d'études d'algorithmes théoriques, puis de prouver leur validité par des simulations, et enfin de concevoir le logiciel opérationnel. Il est évident que pour réduire la durée du cycle, il devient nécessaire de l'aménager, et mettre en oeuvre une démarche de type *ingénierie simultanée* qui implique une certaine mise en parallèle des activités.

Les conséquences du pari technologique et la mise en parallèle d'activités, génèrent des risques Projet qu'il faut maîtriser tout au long du cycle de vie.

3. LE CYCLE DE VIE D'UN SYSTEME

Pour AEROSPATIALE MISSILES, le Génie Système repose sur un "modèle" de cycle en "V" (figure 1) qui , par itérations successives aux divers niveaux du Système à réaliser (Système, sous-systèmes, équipements, sous-ensembles ...), permet la mise en parallèle d'activités.

Durant tout le cycle de vie, des processus transverses contrôlent divers aspects des travaux en cours, ou mémorisent des informations.

4. REDUIRE ET MAITRISER LES COUTS AU NIVEAU SYSTEME

La démarche retenue consiste à satisfaire le "**juste besoin**" en réutilisant au maximum les résultats globaux ou partiels de travaux antérieurs.

A partir d'une expression de besoin du Client, la démarche consiste à réaliser les étapes suivantes :

4.1 Identifier le juste besoin

Pour toutes les phases du cycle de vie du Système, depuis la demande initiale jusqu'au retrait du Système, il s'agit d'identifier les fonctions et les performances à réaliser. Ceci concerne les phases de Faisabilité, Définition, Développement, Production, Utilisation (Mise en service, Soutien Logistique), Retrait du service. Cette étape a pour but de ne pas-réaliser des fonctions ou performances non demandées, ou de ne pas satisfaire le besoin exprimé.

Ce "juste besoin" est atteint en pratiquant une analyse fonctionnelle, et se concrétise par un Cahier des Charges Fonctionnel (CdCF). Pour éviter des incompréhensions sur le besoin, le "Client" est impliqué dans ce processus.

Tout ou partie du besoin ayant peut-être déjà été satisfait dans des projets antérieurs, une *recherche de l'existant* est effectuée. Ainsi, tout ou partie des Analyses Fonctionnelles d'autres Systèmes peuvent être réutilisés et réduisent la durée et donc le coût de cette activité.

4.2 Rechercher les solutions satisfaisant les fonctions identifiées.

Pour chacune des fonctions identifiées dans le CdCF, les spécialistes du domaine procèdent à une recherche d'architecture (concepts et/ou solutions) satisfaisant la fonction. Les fournisseurs (internes ou externes) sont consultés afin de fournir des informations sur la faisabilité et le coût de la solution.

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

Tout ou partie des fonctions ayant peut-être déjà été satisfait dans des projets antérieurs, une recherche de l'existant est effectuée. Ainsi, en tenant compte de ***l'expérience capitalisée*** (technologie, faits techniques, contraintes, solutions rejetées...), tout ou partie des architectures d'autres Systèmes peuvent être réutilisés et réduisent la durée et donc le coût de cette activité.

4.3 Evaluer les solutions potentielles.

Plusieurs solutions pouvant satisfaire un même besoin, il est nécessaire de pouvoir les évaluer afin de vérifier la tenue des exigences et d'obtenir le meilleur compromis. C'est dans ce cadre que sont réalisées des évaluations de coût et de sûreté de fonctionnement, ainsi que des simulations numériques.

4.4 Choisir la solution.

En fonction des résultats des évaluations et simulations, ainsi que de critères concernant les risques, la qualité et l'intérêt d'être innovant, un choix est effectué et justifié.

En fonction de la finesse de définition recherchée, les étapes ci-dessus sont à nouveau itérées; la solution retenue devenant le besoin de niveau inférieur à satisfaire.

4.5 Regrouper les solutions.

Selon les possibilités techniques ou stratégiques, les éléments de solutions sont regroupés en équipements et/ou produits logiciels. Ainsi un équipement ou produit logiciel peut participer à plusieurs fonctions, et une fonction être répartie sur plusieurs équipements et/ou produits logiciels.

Ce regroupement dit en *"chaînes fonctionnelles"* montre la très forte imbrication du matériel et du logiciel, et justifie l'affirmation initiale " le coût du logiciel ne peut être isolé de celui du reste du Système".

4.6 Spécifier le besoin.

Le résultat de toutes ces itérations se concrétise par la rédaction de Spécifications Techniques de Besoin (STB) correspondant aux divers niveaux de profondeur de l'Analyse.

En résultat des divers niveaux d'itération on dispose des STB du Système et des Sous-Systèmes. Parmi elles on peut citer la STB du Système de Traitement de l'information (STI).

5. REDUIRE ET MAITRISER LES COUTS AU NIVEAU DES STI

Pour réaliser un STI, il est nécessaire de spécifier puis développer l'ensemble des équipements et/ou des logiciels jugés nécessaires.

5.1 Historique

Initialement AEROSPATIALE MISSILES réalisait de manière classique, l'analyse et le développement des logiciels des systèmes d'armes selon un référentiel qui a justifié l'attestation AQAP13 (AQAP110 en cours).

Par la suite, *pour réduire les coûts des STI et augmenter la réactivité* (corrections de logiciels), AEROSPATIALE MISSILES a mis en place LOCI (Logiciels Opérationnels en Conception Intégrée). Cette méthode a pour but d'effectuer la meilleure adéquation matériel/logiciel et d'optimiser le processus de développement de la partie commune à l'ensemble des logiciels qui concourent à l'élaboration des versions successives du logiciel opérationnel (figure 2), c'est-à-dire :

- les modèles de logiciel opérationnel pour la simulation numérique de référence et pour la simulation avec éléments réels,
- le logiciel opérationnel lui-même.

5.2 Description de la Méthode LOCI

La méthode LOCI vient en complément du référentiel méthodologique de développement logiciel. Elle indique les actions à entreprendre pour réaliser efficacement le Système de Traitement de l'Information des Systèmes d'Armes. Elle comprend 2 phases :

<u>phase 1 de développement</u> (figure 3)

Une équipe intégrée prend en compte les travaux algorithmiques, les contraintes fonctionnelles et matérielles de la machine cible et de la simulation avec éléments réels (contraintes du temps-réel, précision des calculs liée aux caractéristiques des calculateurs opérationnels, règles méthodologiques, ...), afin de produire :

- une première version de simulation numérique de référence,
- une STBL (Spécification Technique de Besoin des Logiciels),
- une STB (Spécification Technique de Besoin) des moyens matériels.

On dispose alors d'une simulation numérique de référence qui contient les composants logiciels compatibles avec le logiciel opérationnel et la simulation avec éléments réels. Cette simulation permet l'établissement de jeux de tests qui seront utilisés pendant tout le développement du système.

En réponse à la STBL, le logiciel opérationnel est réalisé. Ses composants algorithmiques remplacent alors les composants logiciels correspondants de la simulation numérique de référence. Dès lors, tout au long de la durée de vie du logiciel, les composants algorithmiques sont communs :

- à la simulation numérique de référence,
- au logiciel opérationnel,
- à la simulation avec éléments réels.

Les simulations s'exécuteront donc avec le code écrit pour les composants algorithmiques du logiciel opérationnel.

<u>phase 2 de maturité (figure 4)</u>

Après la phase de développement, des modifications du Système de Traitement de l'Information peuvent être décidées; d'autres versions se succèdent alors.

Dans des cas exceptionnels dépendants de la nature des modifications, il peut être nécessaire de revenir à l'une des étapes représentées par les cases en pointillé sur la figure.

En règle générale la modification est uniquement de nature algorithmique (commune au logiciel opérationnel et aux deux simulation); les modifications sont alors réalisées par l'entité chargée de la conception des algorithmes. Après codage des modifications, cette entité procède aux tests liés aux modifications et aux tests de non-régression de la partie algorithmique du logiciel.

Lorsque ces tests sont terminés, la nouvelle version des algorithmes est mise en référence, à disposition de l'entité chargée de la réalisation du logiciel opérationnel. Cette entité procède à son tour aux tests d'intégration et de validation liés aux modifications et aux tests de non-régression du logiciel opérationnel.

Lorsque les étapes de tests ont été effectuées avec succès, le logiciel opérationnel contenant la nouvelle version d'algorithmes est livré à l'entité chargée de la validation fonctionnelle, laquelle procède alors aux tests de la simulation avec éléments réels.

Cette organisation implique que tous les membres des équipes intégrées utilisent la même méthodologie et les mêmes outils, selon une modulation tenant compte du degré d'avancement (produit d'étude ou produit en phase finale). Ceci est facilité par un Atelier de Génie Logiciel qui offre en plus des possibilités de réutilisation de l'existant (programmes ou modules).

6. REDUIRE ET MAITRISER LES RISQUES

Une analyse des risques du Projet est faite, lors de la phase de définition. Cependant la notion de pari technologique et la forte dépendance matériel/logiciel entraînent de nombreux risques qui se répercutent sur les délais et coûts des développements. Il est donc nécessaire d'identifier et maîtriser tous les types de risques pouvant survenir pendant le cycle de vie du Système. Les risques potentiels concernant un logiciel peuvent être liés au logiciel lui même, mais aussi trouver leur origine dans d'autres éléments du Système; il n'est donc pas réaliste de traiter ces risques de manière indépendante.

7. L'ORGANISATION MISE EN PLACE

Pour aider à la démarche décrite, des méthodes et/ou outils sont mis à la disposition de tous les acteurs concernés. Les activités de Génie Système et de Génie Logiciel sont très liées, il en résulte qu'un certain nombre de méthodes et outils leur sont communs; c'est notamment le cas de la capitalisation des travaux antérieurs. Pour cette raison AEROSPATIALE MISSILES dispose d'un *Atelier de Génie Système et Logiciel* qui peut arbitrairement être divisé en deux.

7.1 Atelier Système

Il comprend des outils à prédominance Génie Système, mais aussi des outils partagés avec le Génie Logiciel. Ainsi, outre les outils classiques (gestion de configuration, gestion de projets, gestion documentaire...), cet Atelier comprend :

- un outil d'aide à l'Analyse Fonctionnelle et à la Recherche d'Architectures (AFERA)
- un outil de capitalisation des travaux antérieurs (ACCES)
- des outils de maîtrise des risques Programmes (CMT)

7.2 Atelier Logiciel

AEROSPATIALE MISSILES réalise des projets en coopération nationale ou internationale. Chaque partenaire ayant ses propres méthodes et outils et souhaitant les utiliser, il est nécessaire de s'adapter en utilisant certains de leurs outils, tout en respectant et améliorant l'ensemble référentiel qui a justifié l'attestation AQAP13. De ce fait l'Atelier ne peut être de type intégré, mais plutôt de type "boîte à outils" structurée autour d'une structure d'accueil encapsulant un Gestionnaire de Configuration du Logiciel.

Une des conséquences négatives de ces contraintes de coopération, se retrouve dans le coût du Maintien en Condition Opérationnelles (MCO) des outils de l'Atelier. La période de MCO d'un Système pouvant aller au delà de 30 ans, il est évident que le problème devient rapidement critique, et qu'il a été nécessaire d'établir une politique de MCO.

Cet atelier comprend des outils classiques du commerce tels que :

- méthodes et outils (SA/RT, SA, SD)
- méthodes et outils orientés objet (OMT, OOA, OOD), peu utilisés pour les logiciels embarqués
- langages ADA, C, C++ ....(compilateurs natifs et croisés)

Des travaux sont en cours pour permettre la réutilisation de modules (ou programmes entiers) capitalisés avec les moyens prévus dans l'Atelier Système.

8. DESCRIPTION D'OUTILS SPECIFIQUES

Pour aider les utilisateurs à réaliser la démarche indiquée ci-dessus et satisfaire d'autres besoins internes, des outils spécifiques ont été réalisés ou sont en cours de développement. Parmi eux :

8.1 AFERA

AFERA (aide à l'Analyse Fonctionnelle et à la Recherche d'Architectures) est un outil interactif pour groupes de travail. Il aide à appliquer la méthode d'Analyse Fonctionnelle (AF) décrite dans le document AFNOR NFX 50-150, et génère un CdCF dont le formalisme est paramétrable. Il aide aussi à décrire les architectures qui permettent de réaliser les fonctions identifiées

En posant des questions, il guide le groupe de travail dans chacune des étapes de la démarche. Il est possible de le personnaliser en ajoutant ou retranchant des questions

Il vérifie la traçabilité entre le CdCF et l'expression du besoin initial ou reformulé (description écrite des missions et contraintes). En effet la reformulation du besoin, peut être nécessaire pour diverses raisons et notamment suite aux résultats infructueux ou non satisfaisants de la Recherche d'Architectures.

Il est capable de gérer plusieurs niveaux d'AF et d'en assurer la cohérence et la compatibilité.

Il aide à vérifier la cohérence entre les critères de performance de chaque fonction et les résultats obtenus par le produit réalisé.

Il permet au groupe de travail de s'inspirer d'AF ou d'Architectures déjà existantes. Pour identifier des AF et Architectures existantes, la recherche est effectuée dans ACCES, à partir d'expressions de besoins identiques ou analogues.

8.2 ACCES

ACCES (Atelier de Capitalisation des Connaissances et d'Exploitation du Savoir-faire) est un outil qui prend en compte les connaissances formalisées et non formalisées. Il est accessible de manière interactive, ou par couplage avec d'autres outils.

C'est une mémoire du savoir-faire comportant l'expression des besoins, les solutions retenues, les solutions voisines, la justification des choix, et les retours d'expériences.

Il fournit la réponse et son contexte à un problème posé (besoin en termes de performances, d'exigences fonctionnelles, de coûts et délais) ainsi qu'à un thème de recherche (historique des connaissances et des faits techniques relatifs à un sujet donné) tout en orientant au mieux l'utilisateur dans la formulation de ses questions.

L'outil respecte les règles de confidentialité, et s'adapte aux canaux de circulation des informations de l'Entreprise.

Il est en permanence possible de l'enrichir, car son but est de capitaliser des connaissances "vivantes".

8.3 CMT

CMT (Criticality Management Tools and procedures) est un ensemble d'outils permettant la Maîtrise des Risques Projet. Il est développé en coopération avec DNV (Det Norske Veritas) et NDA (Norwegian Defence Authorities).

Cet ensemble d'outils et procédures à prédominance interactive permet, à partir d'éléments descriptifs du projet (ex: Gestion de Projet), d'identifier et évaluer les incertitudes et les risques (techniques, économiques, contractuels, politiques ...). Pour les risques inacceptables, il suggère des actions préventives ou correctives visant à les réduire ou à les supprimer. Le choix des actions à mettre en oeuvre s'appuie sur des outils d'aide à la décision.

Il permet de recueillir l'expérience acquise en matière de gestion de risques sur différents projets. De ce fait il "s'auto-enrichit" en matière de définition des risques potentiels et des plans d'actions associés.

Il permet de planifier la gestion du risque (Plan de Management des Risques), et de suivre l'évolution du risque ainsi que l'efficacité des actions mises en oeuvre.

Il est utilisable aussi bien pour un "Portefeuille" de projets que pour un projet complet ou une partie de projet.

9. Conclusion

Comme on vient de le voir, l'optimisation des coûts du logiciel est bien complètement dépendante de ceux du Système. Aussi la démarche et les outils proposés aident efficacement à maîtriser les coûts de développement des logiciels.

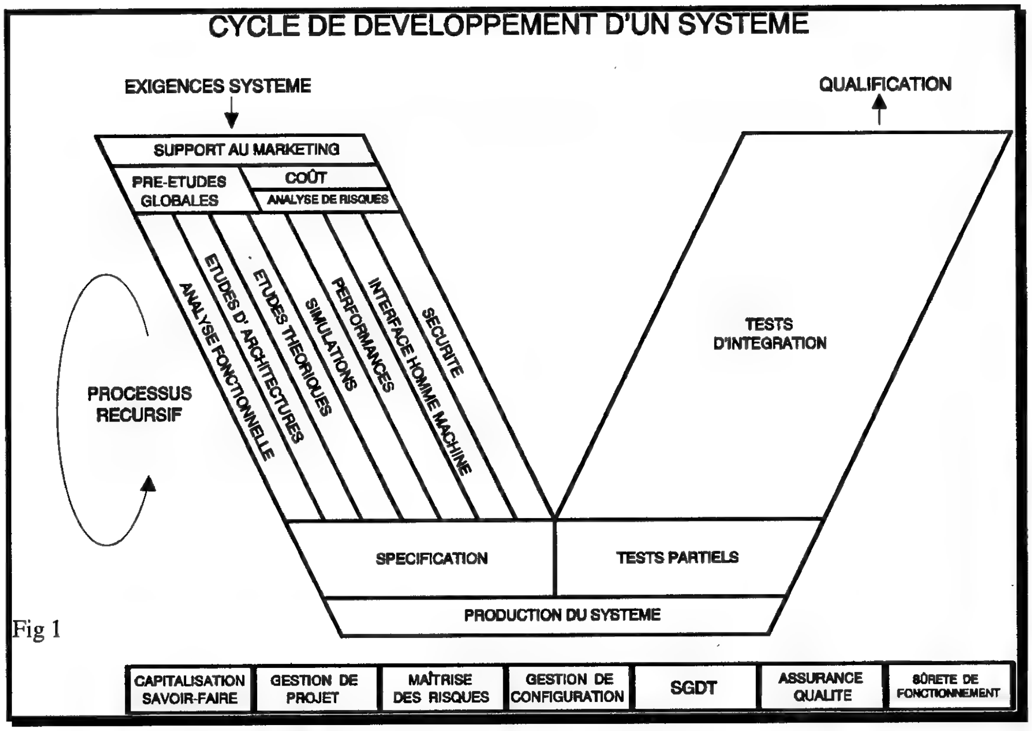


Fig 1

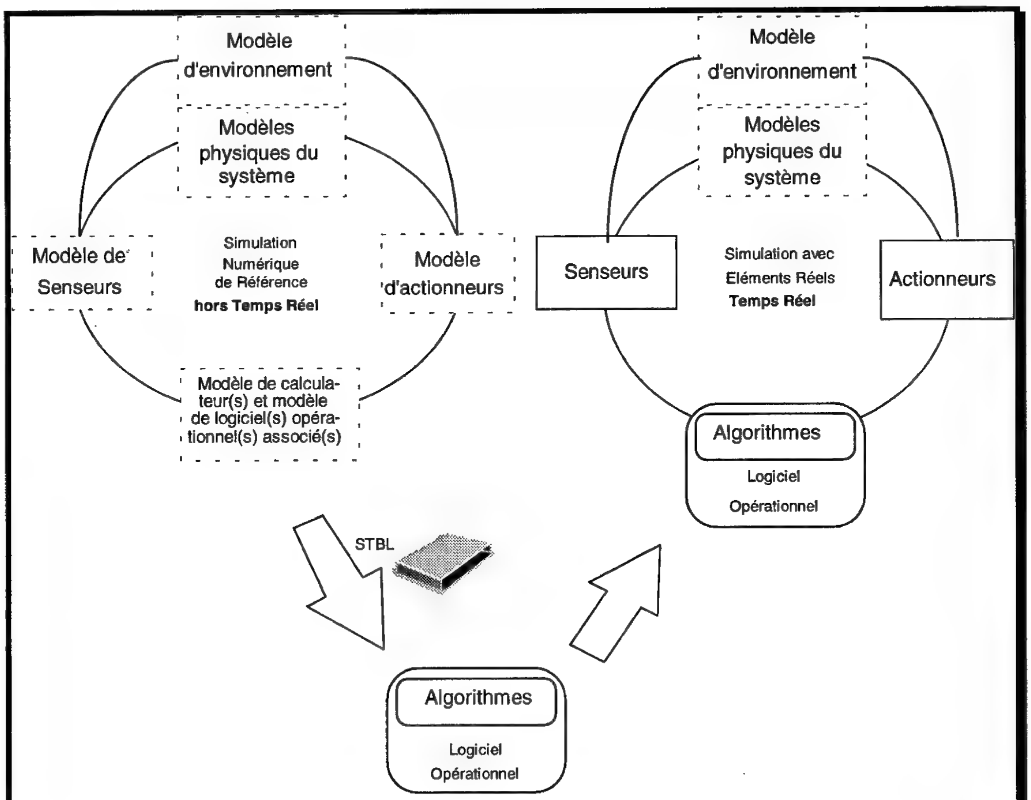
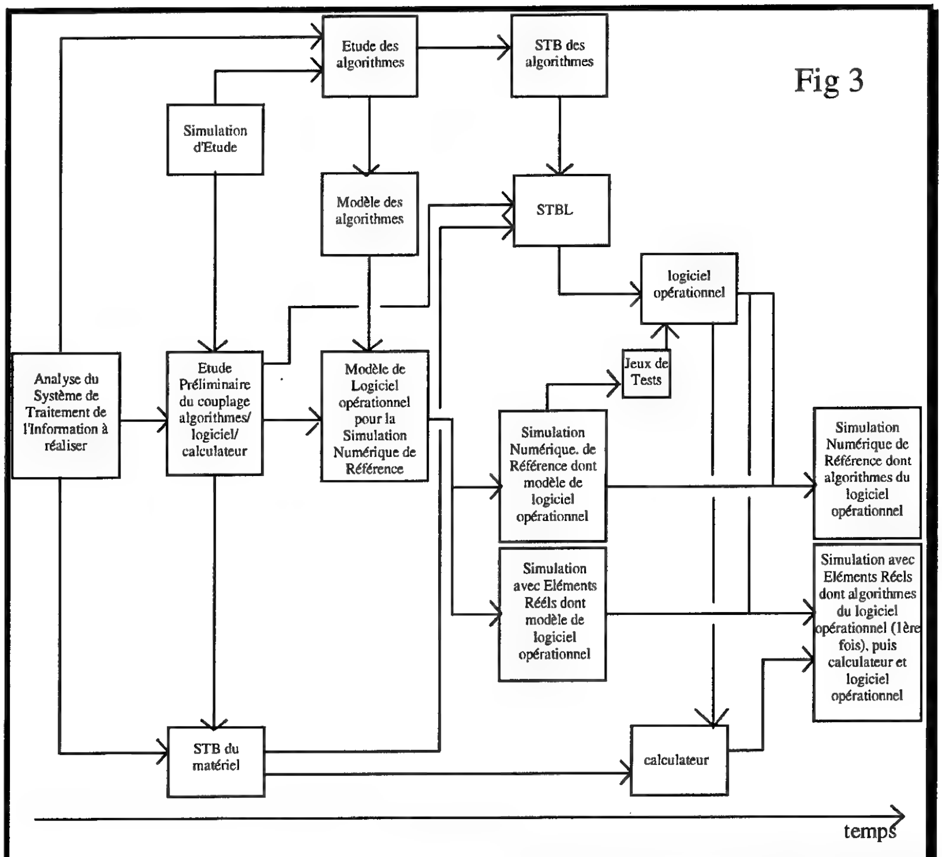
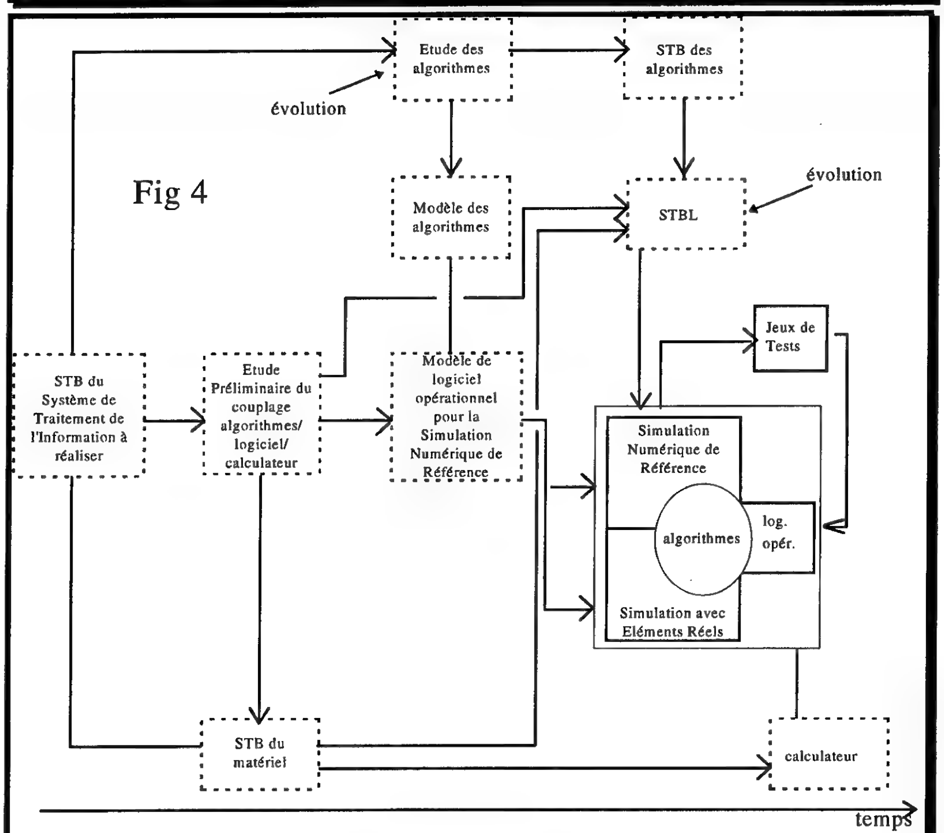


Fig 2

Système de Traitement de l'Information
(Equipement(s) Calculateur(s))



PHASE 1



PHASE 2

THE VALUE OF S&T IN AFFORDABILITY

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SUMMARY

Science and Technology (S&T) programs can have critical impact on the cost of aeronautical systems. The problem is to teach S&T personnel how to deal with the impact that their technologies have on cost as well as they deal with the technical performance impacts. The U.S. government focus on affordability in defense system procurement has provided a timely opportunity for initiatives to be developed and put in place. This paper discusses some of those government initiatives and some of those found in industry. Results are presented. The benefit of addressing four areas concurrently will be discussed. They are: Culture change, including the use of Integrated Product and Process Development (IPPD) and Integrated Product Teams (IPT), use of appropriate metrics, emphasis on transition of technologies to acquisition programs, and timely education and training.

1. INTRODUCTION

Within the U.S. government-industry-university defense effort "affordability" has come to mean the application of initiatives in business, design and manufacturing, and industrial base practices to drive down the cost of weapon systems. Most of the initiatives have been focused on the so-called big "M" aspects of manufacturing. The Defense Manufacturing Council was charted in 1994 to accelerate the application of DoD Affordability Initiatives.

R. Noel Longuemare, then U.S. Principal Deputy Under Secretary of Defense for Acquisition & Technology, in his keynote address to the Science and Technology (S&T) Affordability Workshop in October 1996 (Ref 1), discussed the role of science and technology in implementing the Department of Defense's (DoDs) strategy for affordability.

Commercial role models had shown that reductions of 30-50 percent were possible in defense system costs and development time. Building block steps have been taken to achieve the objectives. Some of them are:

- Moved away from MILSPECS and toward the use of commercial processes and standards.
- Established a requirements process where only a critical few user needs are firm, and the details of how to achieve them are left to the contractor.
- Implemented Integrated Product and Process Development (IPPD) and Integrated Product Teams (IPTs) as best practices throughout DoD.
- Initiated Cost As an Independent Variable (CAIV) in a number of flagship programs.
- Changed acquisition laws and regulations, streamlined procurement practices.
- Began the education and culture change process in the acquisition workforce.

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

Furthermore, there has been a growing emphasis on affordability in S&T programs. The Workshop was organized to focus on four areas:

- **Cultural changes necessary within the S&T community, including the use of IPPD and IPTs to affect affordability.**
- **Definition and use of Metrics in tracking and achieving affordability objectives.**
- **More effective transition from S&T programs into acquisition programs.**
- **Education and training to implement and support the above.**

James Sinnett, Corporate Vice President for Technology at Boeing (then McDonnell Douglas) and chair of the Multi-association Industry Affordability Task Force, offered an important perspective on the role of S&T in affordability. He told the Workshop audience that:

"I happen to believe that S&T forms the basis for our National Security and strong Defense posture. There may be little argument amongst us about the role which S&T has played in the growth of warfighting capability, particularly in the 20th Century. What may be more contentious is whether we have been able to provide that capability in the most timely and efficient manner.

We seemed to have grown into a protracted era of specialization. Every time there was a new discovery, we grew and educated a new specialist to deal with it. At the same time, we distinguished between Basic Research, Exploratory Research, Advanced Development, and Product Development in virtually each of the resultant component specialties. In the extreme, many component technology initiatives were developed in a vacuum until it became time to integrate (in some cases, competing) ideas into a product for the warfighter; often without a sense of leverage. But, most certainly, we all had "the good sense" to maximize performance! We used to believe that fielding balanced technical solutions was difficult. Now we must field balanced technical and supportability solutions...all at a cost we can afford!

We have spent 90 years in the Aerospace side of the business providing technology to drive us toward flying higher, faster, and farther, turning tighter turns, accelerating and decelerating quicker, seeing better (and not being seen better) ... with little focus on the cost of these achievements; after all, "those were the requirements". We need to come to grips with the real issue of the 1990's into the 21st Century: How to develop and apply the technology to make our weapon systems affordable...and, by the way, still meet the "requirements" and warfighter's needs.

Now, one can easily get caught up into a lengthy discussion about what is technology and what is not. Let's please avoid that pitfall, for it often just diverts us from the purpose of our quest. Let's capture the mindset that S&T is the great enabler ... perhaps common sense is the pathway for application.

Common sense tells us that:

- products consist of independent functions which are enabled, and often leveraged, by a mix of technologies
- there may be different issues and differing risks associated with each element of the life cycle
- (along with lots of experience) there is a "knee in the curve" of performance vs cost; and a family of curves for different approaches
- we should leverage the individual technologies and the technology teams for an integrated product
- to be more affordable we must develop a cost awareness.

An "Affordability Culture" tells us to look at the world differently. For example, given a mission performance requirement:

- different approaches may lead to acceptable alternative solutions
- reduced drag means less fuel, less propulsion, less wing, and a smaller aircraft ... at less cost
- improved structural efficiencies means less structural weight, smaller wing, less propulsion, less fuel...at less cost
- improved C4I and netted situation awareness <u>may</u> mean fewer autonomous on-board sensors...at less cost
- better integration of subsystems and subsystems technologies will mean less power, weight, volume and cooling...at less cost
- increased automation may mean greater redundancy and fewer people, either on-board or in the infrastructure...at less cost
- use of commercial off-the-shelf (COTS) technology hardware and software, balanced with providing environmental isolation as a cost trade and drawing upon an "open systems architecture" should mitigate technological obsolescence...at less acquisition and support cost
- Manufacturing technology, focused by design for manufacturing and assembly (DFMA), can improve quality while reducing the number of parts, number of tools, and number of fasteners...at less cost
- modeling and simulation technology already plays a significant role in reducing development cycle time for pilot vehicle interfaces, whether on-board or off-board...at less cost
- extension of modeling and simulation in the context of adjudication of requirements, design concepts and technology payoffs to the warfighter can provide a dramatic effect on a systems concept and quality of the solution...at less cost
- extension of modeling and simulation to the area of design for manufacturing, producibility, and supportability can provide an inherent reduction in design, fabrication, assembly and support time and improved product quality...at less cost.

We need to look at some of these same tools and techniques for reducing our support infrastructure. Every dollar spent for support cost is one less dollar available for modernization. Through some of these same technology tools and techniques we may be able to introduce modernization through spares on a broader scale; drawing upon the innovative approaches such as those championed for the US Army."

The role of Science and Technology (S&T) in US DoD initiatives and the continuing role of S&T to affect affordability in defense and in the commercial sector is the subject of this paper.

2. <u>KEY GOVERNMENT S&T AFFORDABILITY INITIATIVES</u>

There is a focus by the US DoD in four key areas to develop and implement S&T affordability initiatives. The four areas: Culture Change (including IPPD and IPTs), Metrics, Transition, and Education & Training are discussed in this section as viewed by the US Air Force. In addition, the DoD Technology Development Approach will be discussed. It emphasizes cost goals in S&T.

<u>2.1 Culture Change</u> (IPPD & IPTs)

Science and Technology customers (the Acquisition world -- including industry) have changed the emphasis in their requirements for technology due to lower acquisition budgets and different threats. No longer are these customers interested in maximizing performance and accepting the resultant costs and risks. There is a dramatically increased emphasis on improving performance at lower costs along with a clear understanding of the risks of inserting new technologies. To be the preferred technology supplier, S&T personnel must meet this changing customer need.

As a result of this new environment, Science and Technology executives recognized the

need to change the mind-set of researchers and engineers. IPPD and the use of Integrated Product Teams (IPTs) was recognized as a proven method, employed and demonstrated in acquisition, to systematically manage priorities, performance, cost and risk. It was recognized that by focusing on IPPD and IPTs, the S&T community can address many of the key elements that drive the affordability of technologies that are transitioned to weapon systems. For IPPD to be effective, however, S&T personnel must change their culture to accept and implement the concept. Education and training becomes extremely important in this culture change, as S&T personnel must have the skills, knowledge, motivation and the environment to make it happen. Also, for IPPD to be implemented, it was recognized that S&T senior and middle management must be visibly involved and provide leadership - thus culture change must occur with the managers as well as the researchers.

2.2 Metrics

Metrics are needed that emphasize the key indicators of the cost impact(s) of S&T. While section 3.1 of this paper gives an example of metrics used by industry, the DoD continues to develop their metrics. Selected advanced development (6.3) programs are underway using various metrics in order to learn about each and to derive guidelines for future programs. Metrics for three different time periods are envisioned for the education and training component of the Air Force program. They are listed below.

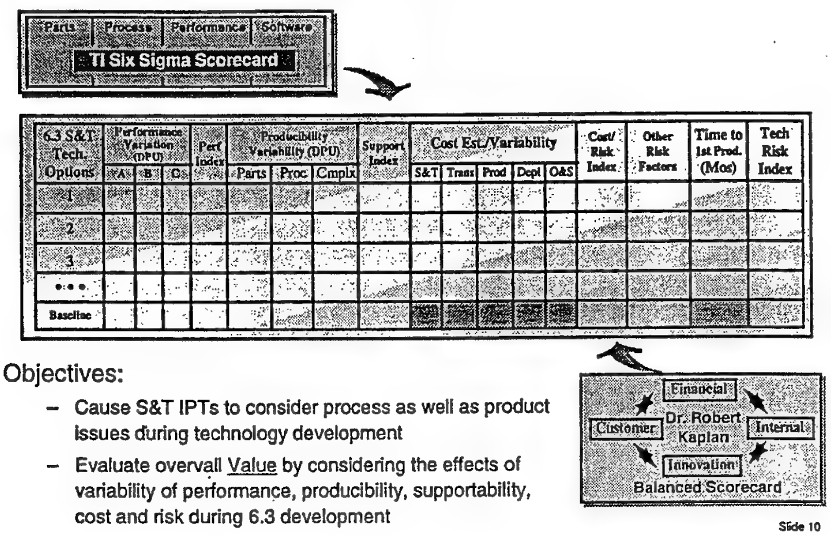
Time Period	Desired Response	How Measured (examples)
Near Term	Trainee Completions and Response	• No. of individuals and IPT's trained • Degree of satisfaction • Key Concepts explained? • Adds value - Teams actually apply it • Tests/evaluations
Mid Term	Impact on S&T Project(s)	• Project organization & mgmt employs IPPD principles • Direct customer involvement in project IPT • Project investment among performance and producibility, supportability, etc • Balanced technology maturity issues addressed in tech transition plan
Long Term	Technology Transition/Customer Relevance	• Customer confidence in laboratory technology maturity assessments • Successful technology transition to acquisition and support customers • Degree of customer support and advocacy for S&T programs

2.3 Transition

The initial IPPD implementation focus for the Air Force has been the advanced development (6.3) programs. The 6.3 programs are typically at the end of the technology development cycle and have transition opportunities identified for specific weapon system customers. When applied to this environment, IPPD methods can address the need to improve the process of transitioning technology to acquisition through tools such as

the "Value Scorecard" (Figure 2.3-1 and discussed below). In order to scope and focus the initial implementation, a subset of the Air Force S&T 6.3 programs were selected as pilots. A total of thirteen programs, selected from across the complete S&T spectrum, are included in the initial experiment. The IPTs associated with each of these programs have helped develop the just-in-time education and training discussed below.

Figure 2.3-1 -The Value Scorecard



The Value Scorecard (figure 2.3-1) has been developed and applied to each of the 13 pilot programs. The value scorecard was derived from the merging of two concepts: 1)The Texas Instruments Six Sigma Scorecard (Ref. 3), and, 2)Dr. Robert Kaplan's (Ref. 4) approach to metrics encompassing the four factors shown on the lower right of figure 2.3-1 (instead of a general Return on Investment). From left to right on figure 2.3-1, the scorecard allows a comparison of each design alternative in terms of the expected variation in performance, producibility, supportability, and cost and risk. The "language of defects" (the probability of encountering a defect) is used to depict the variability and is common across the scorecard.

Major benefits expected from use of the Value Scorecard are: 1)that it will enable the technology developer to present a balanced view of each technology alternative, 2) to identify risk earlier and thereby budget for resolving those risk factors, and finally 3) that it will present to the customer a more comprehensive understanding of the potential cost and risk associated with different technology alternatives that address the spectrum of customer requirements.

2.4 Education and Training

A course was developed using a philosophy of "Do by Learning and Learn-by-Doing" and applying Just-in-Time education and training to individual teams wishing to implement affordability on their specific project. In other words, the team (both Govt and Industry team members) had an immediate need for the training in their project. The overview course focused on identifying critical pieces of IPPD and integrating the results through a Value

Scorecard. Figure 2.4-1 illustrates the Air Force education and training approach. The three day overview course, entitled "Affordable Technology through IPPD" is supplemented by support to the team from an industry systems engineer during the formative phases of the project, and specialized training such as design of experiments, design to cost, as deemed necessary by the team.

Five Modules are anticipated for this course - Following an up-front motivational introduction:

a) Requirements Definition - Interfacing with the customer to fully understand and prioritize requirements.

b) Six Sigma Design - Introduces the concept of variability and it's effects across the entire technology development spectrum.

c) Value Scorecard - Management tool which supports 6.3 technology maturity assessments in response to customer requirements by relating measures of performance, producibility, supportability, cost and risk.

d) Cost and Risk Assessment - Methods and tools used to compute projected costs (e.g. tech transition, acquisition and life cycle) and risk.

e) Enhanced Technology Transition Plan - Builds on existing AF S&T tech transition practices and documents. This represents a business plan to support customer decisions in implementing new technologies in weapons systems.

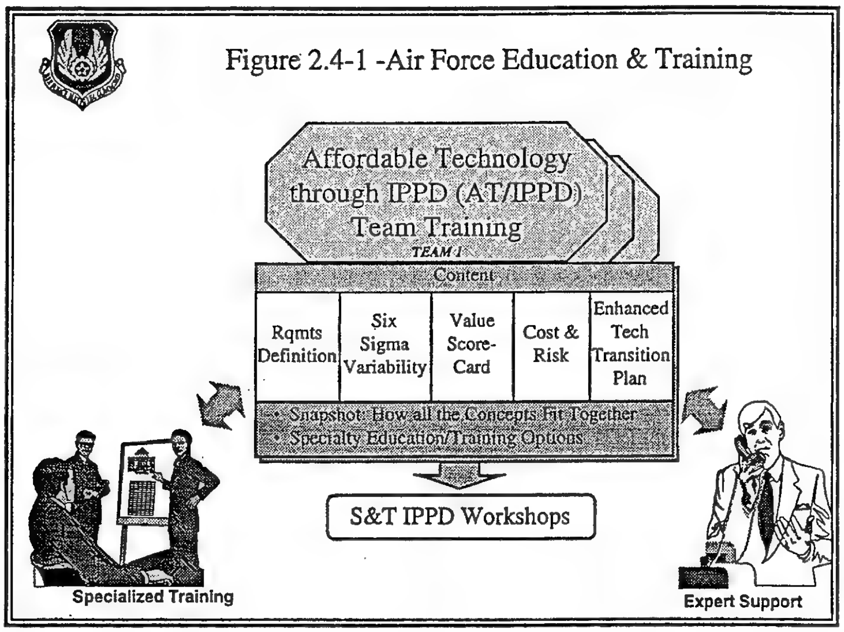


Figure 2.4-1 -Air Force Education & Training

The development of the education and training program discussed above took about three years. Probably another two years will be required to fully understand the ramifications from implementing these concepts. In the mean time, the Air Force is now beginning to focus on IPPD education and training for all S&T 6.3 program managers and 6.2 and 6.1 researchers. It is felt the lesson learned and examples gained from the 13 pilot programs will provide a rational point of departure for this new focus.

2.5 The DoD Technology Development Approach

An approach to develop technologies by establishing specific technology objectives,

the last few years by the Integrated High Performance Turbine Engine Technology (IHPTET) program. The Technology Development Approach (TDA) it pioneered is being extended to much of DoD's S&T Program; furthermore, it has been augmented by the addition of affordability relevant objectives and goals, such as cost reductions in three phases of a system life cycle: RDT&E cost, Production cost, and Operating & Support cost.

The connectivity among technical objectives, air vehicle-level goals, and aircraft system payoffs is shown conceptually in Figure 2.5-1. The corresponding set of quantified objectives, goals, and payoffs for future Fighter/Attack aircraft is shown in Figure 2.5-2. Note that this figure is part of the Fixed Wing Vehicle (FWV) Technology Development Approach (TDA). Also note that half of the goals (shown in the top-right of Figure 2.5-2) are related to cost reduction. Plans to achieve the objectives and goals have been developed. Work has been assigned and progress will be measured to ensure that objectives and goals are achieved

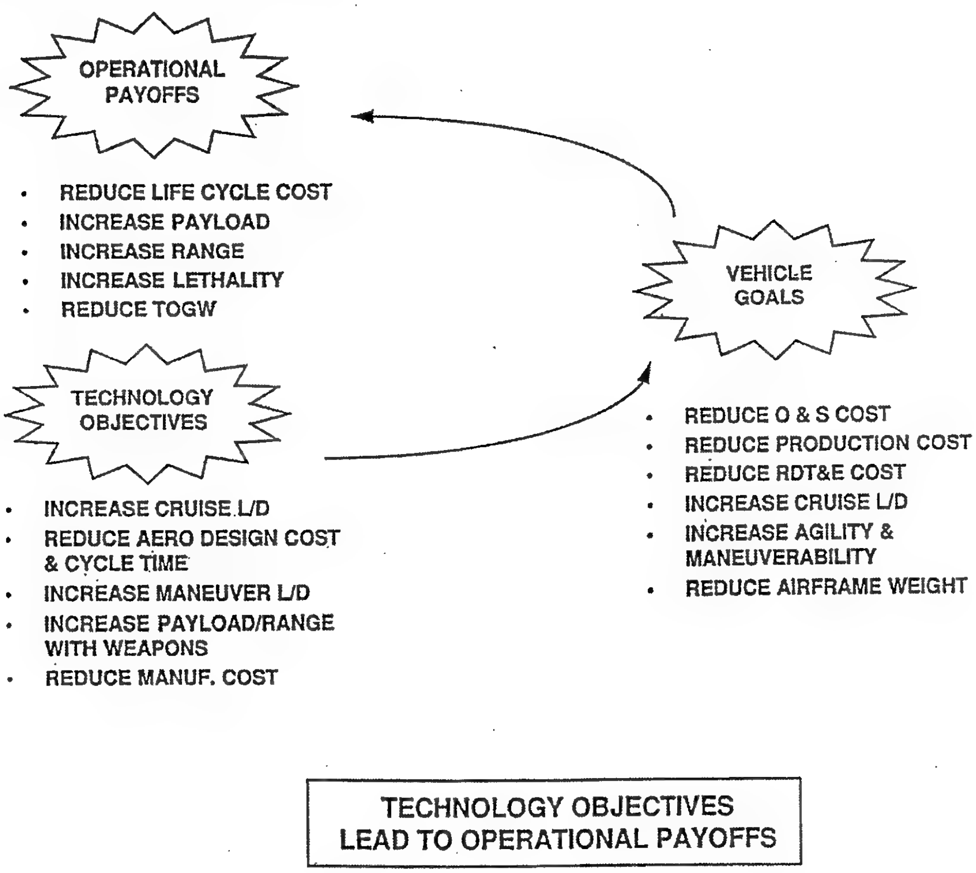


Figure 2.5-1

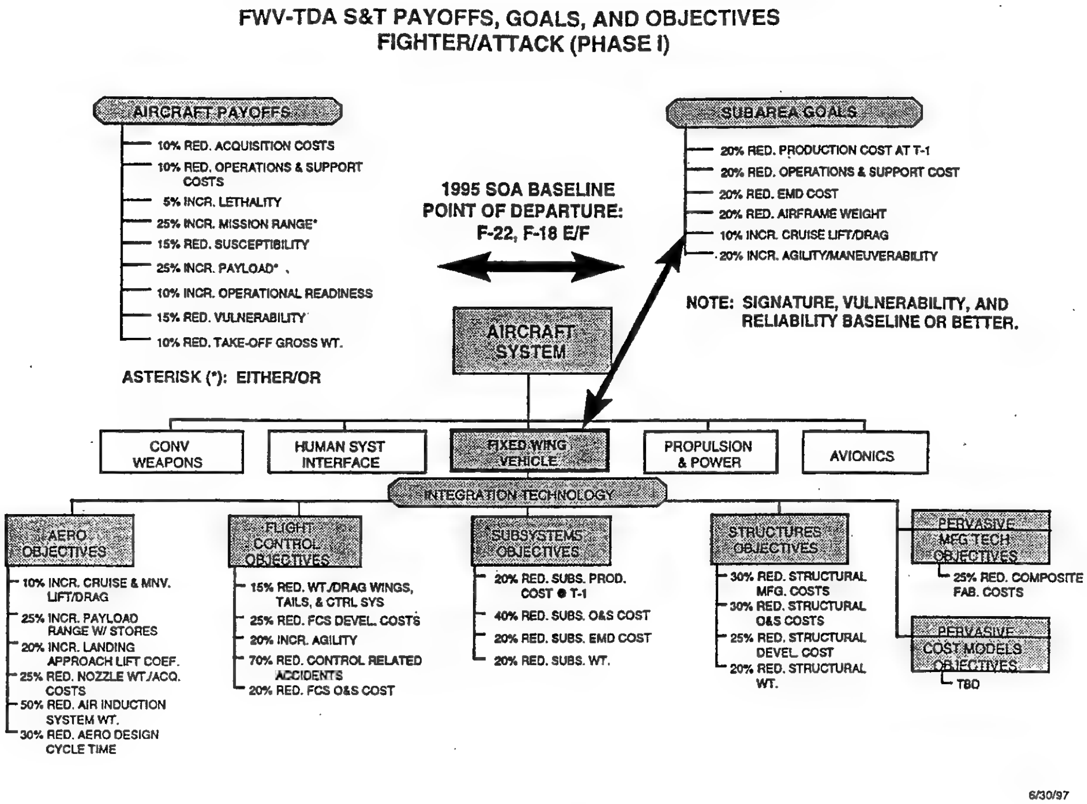


Figure 2.5-2

3. EXAMPLES OF S&T AFFORDABILITY INITIATIVES IN INDUSTRY

At Boeing, in the Information, Space and Defense Systems Group, we have developed an approach to initiate, track, and record progress toward achieving cost reductions. We established an Affordability Steering Team and a database to record and track progress. Figure 3-1 shows the steps in the process used to generate requirements (e.g., aircraft price targets), develop and select among initiatives, manage & track status, and realize the benefits. There is a wide range of sources for the affordability initiatives, such as:

- Product and Process Technology (i.e., S&T) Development
- Capital Improvement Projects
- Design for Manufacturing and Assembly Projects
- Engineering Studies
- Supplier/Sourcing Reviews

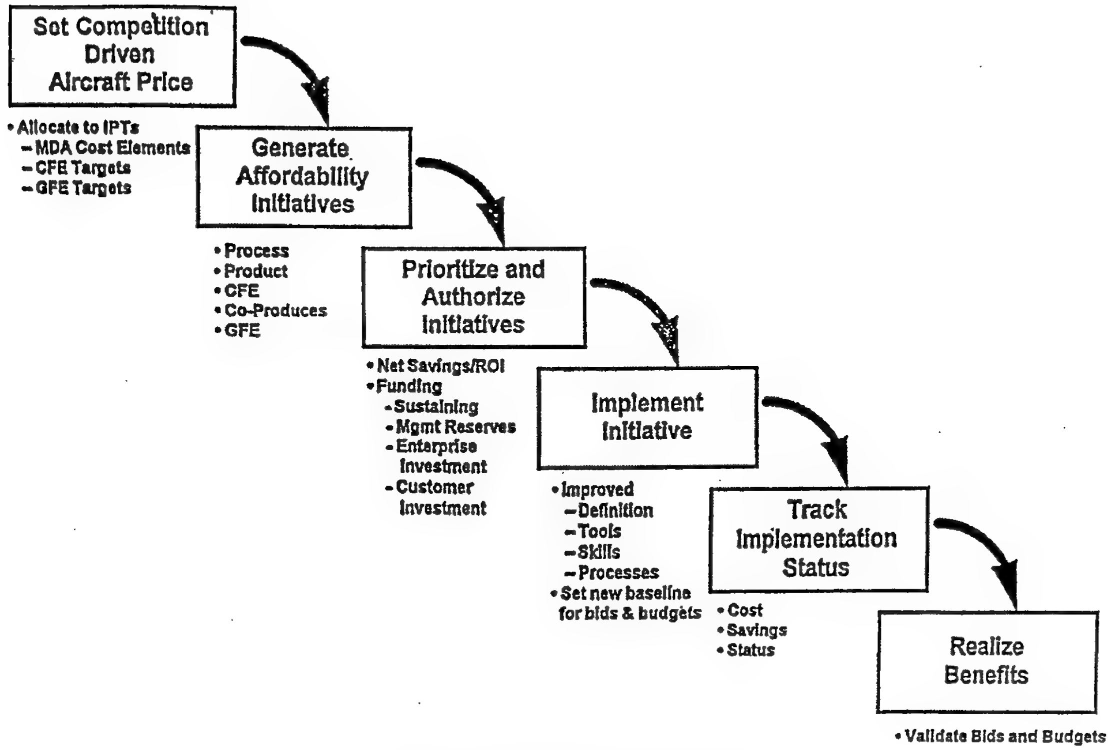


Figure 3-1 Managing Affordability

The critical issue of transitioning technology into products and processes receives special attention. The "pull" for technology must match the "push" from the S&T community. To do that we are improving the process of Technology Transition. That process requires an articulation and understanding of the benefits and the extent that they outweigh risks. The "language of affordability" is the key to articulating technology cost and value benefits and risks.

3.1 Technology Value and Transition

In 1996 our S&T teams in the Boeing (then McDonnell Douglas Aerospace), Advanced Systems and Technology - Phantom Works (AS&T-PW) organization were challenged to estimate the dollar value of technology products and processes delivered to our company programs, and to work closely to transition process technologies into use on the programs and product technologies into production. New in 1996 were the specific team goals and a requirement for S&T personnel to become proficient in "value estimating." An "affordability room" was set-up to display plans & progress for our technology "deliverables" in 1996. One team set out as a pilot program to plan the dollar value and the schedule for 1996 deliverables and to track the results. That plan and results are shown in Figure 3.1-1. For that team, 70 technology products, with an estimated "value" of 100 cost units (related to dollars) were planned. By the end of the year, 39 products had been delivered, 21 of them transitioned with the value impact shown on Figure 3.1-1, that is, of the 100 value units planned, only 65 were achieved for delivered products and by the year end the value of those products transitioned was 36 units. Preliminary lessons learned from the pilot program are summarized here:

- S&T and cost estimating personnel must work closely with program customers to increase their value estimating

skills and to communicate the uncertainty in value estimates.

- S&T programs have risks of failure which must be understood, communicated, managed, and accepted.
- S&T requirements are dynamic and must be accounted for in an adaptive planning and tracking process.
- Technology Transition can be greatly facilitated by use of value and performance metrics (i.e., the "language of affordability").
- The 1996 Technology Delivery and Transition Metrics focused on the Near-Term to the detriment of Long-Term S&T program emphasis.

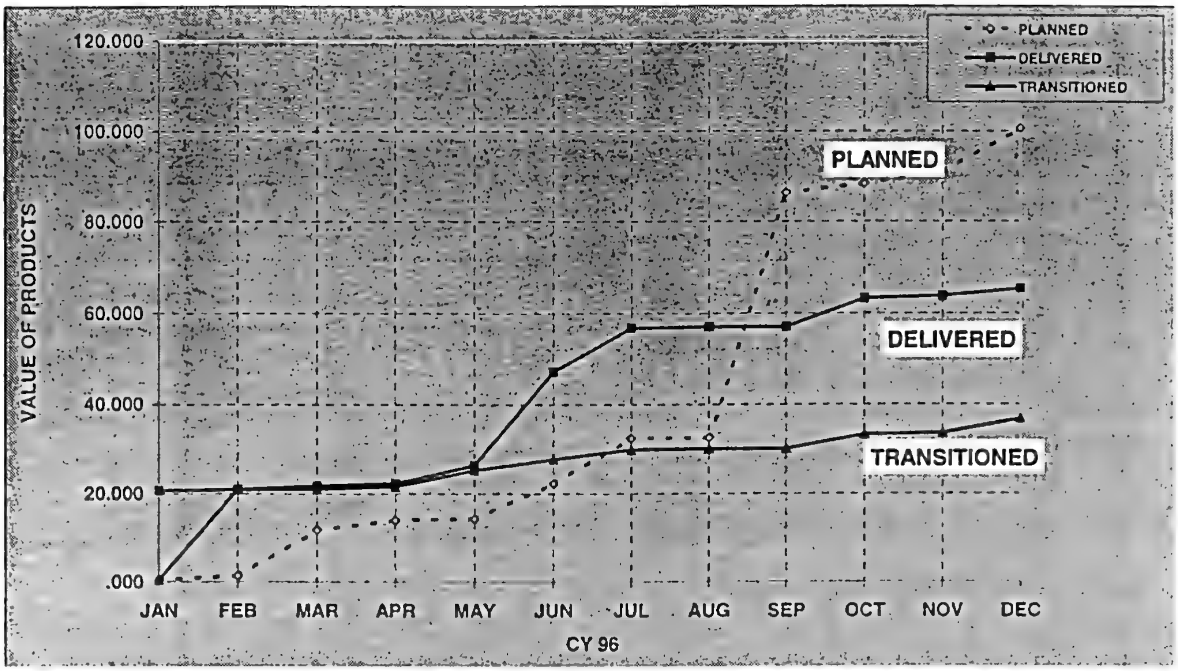


Figure 3.1-1 Planned vs Delivered and Transitioned Technology "Value"

The lessons learned are being acted upon, while the process of measuring TRANSITION VALUE to our company programs has expanded to other S&T teams along with very challenging goals. The last lesson learned is being addressed in 1997 by S&T teams through a new metric and goal - the POTENTIAL VALUE of all S&T programs underway (not just those with near-term deliverables). That helps to balance the long-term and near-term S&T program content.

The cost estimating education process involves supervisors, cost estimators and S&T personnel, (even those in basic and applied research), learning cost elements, and how their technology program could potentially influence the cost elements. This education is done usually through on-the-job training (OJT) where assumptions are made and documented on the potential use of technologies. S&T personnel are learning to treat value/cost estimates as rigorously as they treat technology performance estimates. Teams have created check lists for estimating (near-term) transition value.

Estimating risk of failure and uncertainty in technical and cost performance is receiving current emphasis. Our objective is to handle those parameters as rigorously as we now do

technical performance and as we are learning to do cost and value estimating.

3.2 Examples of S&T Affordability Impacts at Boeing

- Advanced high speed machining and fiber placement composites technology, modern computer engineering tools (a single 3-D digital data base), design and producibility modeling and a virtual reality environment, used by Integrated Product Teams enabled the Hornet Team to produce the first F/A-18 E/F engineering and manufacturing development (EMD) phase aircraft on schedule, on budget, and almost 1,000 pounds under weight. The F/A-18 E/F is 25 percent larger, and much more capable that its predecessor, the F/A-18 C/D, with 40 percent fewer parts (Figure 3.2-1).

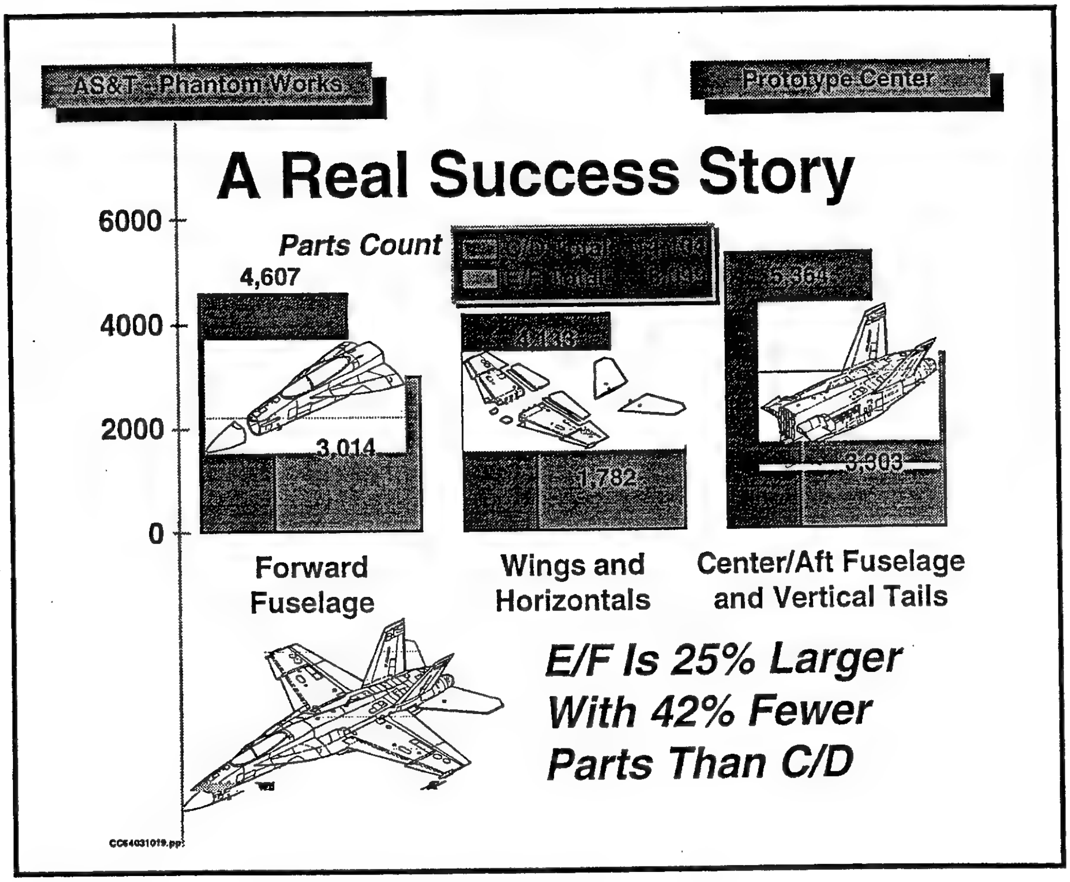


Figure 3.2-1

- Application of Man Tech practices and composites technology to the C-17 horizontal tail, in the "Manufacturing 2005 Program" has led to a newly designed horizontal tail at 53 percent less cost and 20 percent lighter weight than the original, with 85 percent fewer parts and 82 percent fewer fasteners. This was accomplished by an IPT composed of the ManTech Lab, C-17 System Program Office (SPO), Boeing-Phantom Works, C-17 Program at Long Beach and the team at Vought, who is the supplier for the tail. We have recently received change board approval for in line incorporation. Figure 3.2-2 shows the benefits from four other DFMA improvements to the C-17.

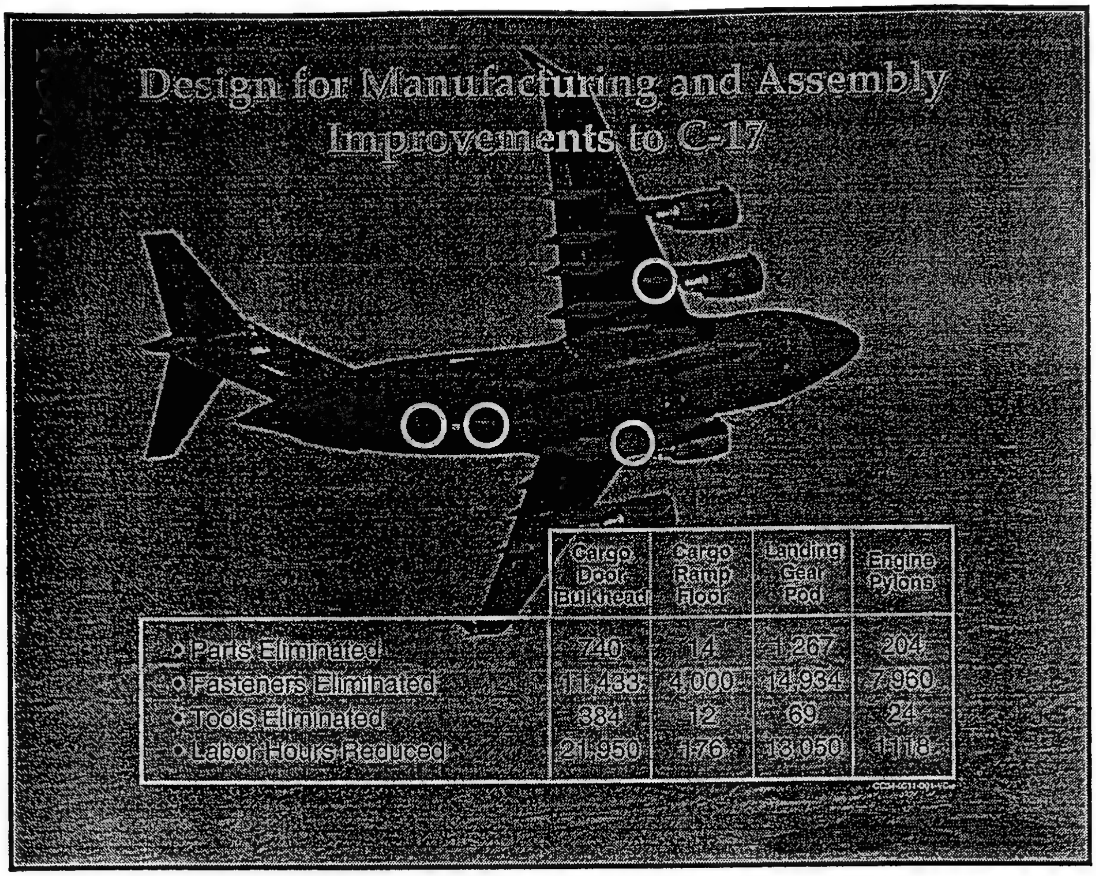


Figure 3.3-2

- Application of modeling and simulation for redesign of the T-45 horizontal tail resulted in design, tooling, and manufacturing plan definition in one-half the cycle time normally expected. Carrying this through to factory lay-out yields reductions of about 20 percent each for factory space, cycle time, and labor hours.
- Virtual reality applied to the F-15 for evaluation of new equipment bays was accomplished in about 140 hours, and identified 18 interference areas not normally identified via traditional Electronic Development Fixture (EDF) means...this is roughly 25 percent less time than the traditional EDF and 90 percent less than a physical mock-up.
- Application of new analytical codes, 3-D solids modeling in a single digital data base, design and producibility simulation, advanced manufacturing and tooling techniques and IPT's which included our partner, NASA, enabled us to produce the X-36 research aircraft in 1/3 the time, at 1/5 the cost experience for like aircraft in the past.
- The combination of Acquisition Reform initiatives, IPT's including our customer and suppliers, and design, manufacturing, and managing for affordability has enabled Boeing and the USAF to demonstrate significant cost, cycle time, and quality gains for the Joint Defense Attack Munition (JDAM) program. A key element is development and demonstration of a low

cost core guidance system...even then improved by a "badgeless" IPT. Other elements include the use of CAIV, incorporation of COTS technology, DFMA, identification of key characteristics and processes, and subcontract streamlining to eliminate MIL specs/std. Since 1993, development time decreased from 64 to 48 months, development cost from $550M to $330M, production time from 15 to 10 years, and production cost from nearly $5B to $2B!

- The Advanced Lightweight Aircraft Fuselage Structure (ALAFS) Program is a Joint Strike Fighter (JSF) technology maturation effort to demonstrate affordable and lightweight structural technologies. The objective of the ALAFS Program is to advance the state of the art in structural technologies from that of the F/A-18E/F and F-22 to that required by the JSF to meet its affordability and performance requirements. The specific objective is to demonstrate the viability of affordable lightweight structure in the most critical of all aircraft assemblies; i.e., the wing/fuselage carry through section to ensure a realistic demonstration of these technologies. The F/A-18E/F is used as the baseline. This provides a firm foundation for requirements, cost, and weight data from which to measure the performance. The weight savings strategy is to increase the amount of composites from the current 27 percent to approximately 48 percent. Unitization of both composites and metallic parts will provide a significant acquisition cost savings. O&S cost savings will be achieved through less weight and parts overall, with much less fatigue and corrosion prone structure (Figure 3.2-3).

Figure 3.2-3

- The Composite Affordability Initiative (CAI) Program is a consortium of U.S. industry companies (Boeing, Lockheed-Martin, and Northrop-Grumman), the Air Force and the Navy. The objective is to develop the tools and technologies necessary to enable

aircraft designers to confidently design an all-composite airframe utilizing revolutionary design and manufacturing concepts to enable breakthrough reductions in cost and weight. Initial spin-off will be for JSF EMD, but other applications are being considered beyond JSF. Where ALAFS increases the composite usage to approximately 50 percent, CAI goes to 75 percent or greater. A primary goal of CAI is to decrease the cost/lb. from $1,000 plus to the $200/lb. range (Figure 3.2-4).

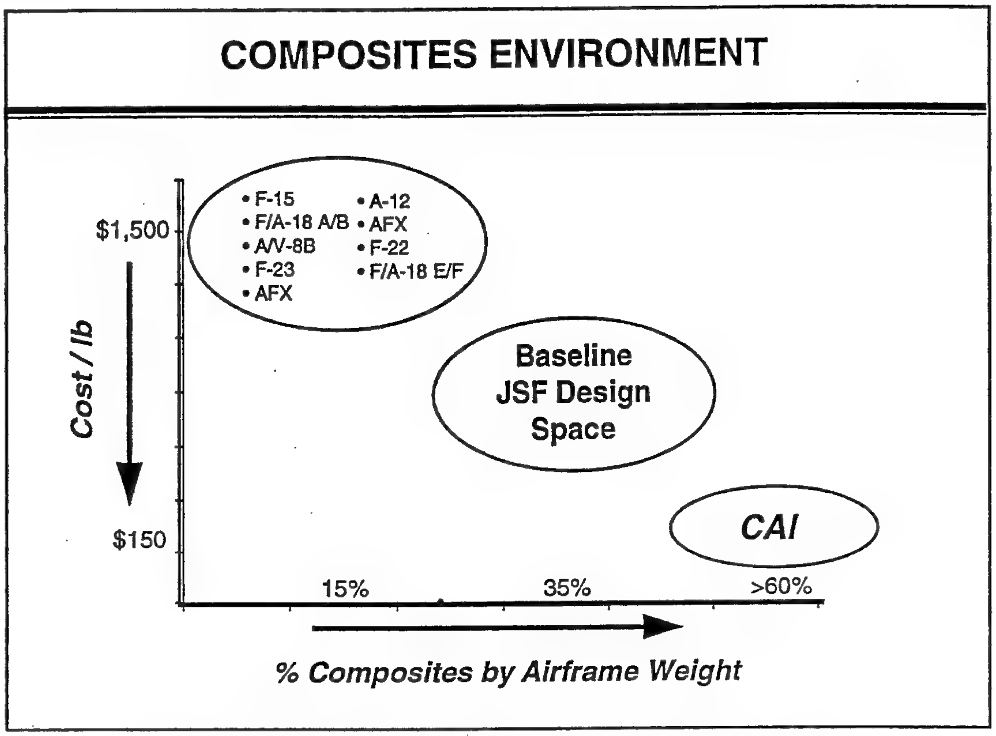


Figure 3.2-4 Impact of S&T on Cost of Composite Structures

Fiber placement technology is one example of how science and technology has worked within the integrated product development environment to produce composite parts for about 20 percent less than the cost of hand layed-up composite systems. Fiber placement is a technology that developed in the 1980's to permit non-autoclave placement and curing of thermoplastic composite resins. This technology was satisfactory for fabricating closed (i.e., cylindrical) structures, however, the temperatures required to place and in-situ cure those resin systems were too high to permit structures with accurate dimensional tolerances to be produced. Residual stresses through the thickness of the composite parts were too high to allow placement of flat parts. At the same time, the composite materials industry was developing thermoplastic tougheners for more conventional resins that allowed these resins to nearly match the toughness standards of the pure thermoplastic resins. While these systems still required autoclave curing, they could be placed and tacked rapidly using fiber placement equipment, then cured in an autoclave using the same tooling used for placement. Laboratory tests of this placement scheme showed the potential for a 15-20 percent cost savings over

conventional hand layed-up and autoclave cured systems.

- What these systems allowed was the development of larger, unitized composite structures that could be cured in one operation and produce a single large part instead of many parts which had to be fastened together to complete the structure. Placement allows lay up of parts much larger than are practical using hand lay up methods. In order to effectively use the fiber placement capability, parts and their tooling had to be designed to make best use of the process in order to minimize the fiber placement time, the number of tools required and the number of parts to be produced. In addition, the layups and structural definition had to be such that the resulting part was as economical as possible. Integrated product development teams, with an emphasis on design for manufacturing and assembly, were key to the effective use of fiber placement as a cost saving development. Early trials, using advanced fiber placement prototyping facilities (Figure 3.2-5), demonstrated that the potential cost savings could be as much as 22 percent below hand layed-up composite structures.

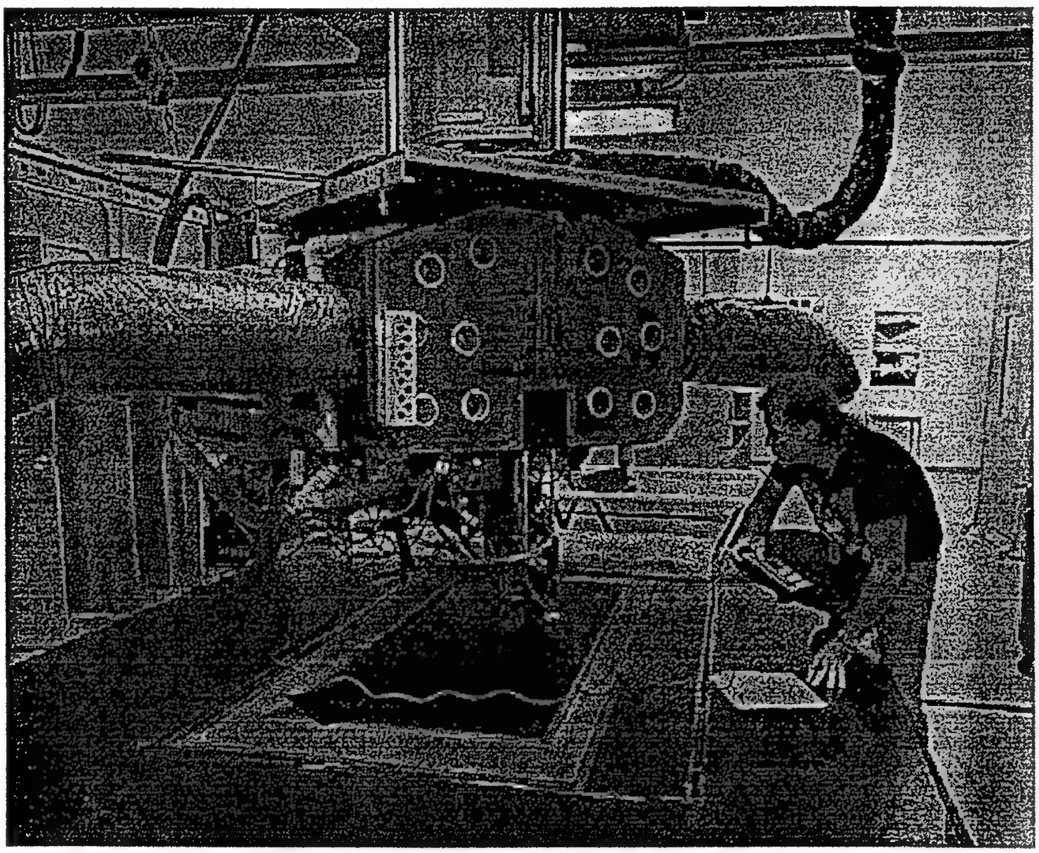


Figure 3.2-5 - Fiber Placement Machine Laying Advanced Tow Materials in Boeing Advanced Manufacturing Facility

In order to realize these cost reductions, the process had to be scaled up to produce part sizes desired for production aircraft. A major capital equipment investment was needed to develop a facility which could produce fiber placed composite parts with placement rates suitable for production. Such a facility (Figure 3.2-6) was developed within a few years, based on the potential cost savings demonstrated by the prototype facility. With this facility in place, production applications could be developed for the F/A-18 and the C-17 which would have impossible only a few years ago. Initial production runs for these aircraft are demonstrating that composite parts, designed for, and fabricated using, fiber placement are demonstrating cost savings in excess of those projected using the smaller prototype fabrication facility.

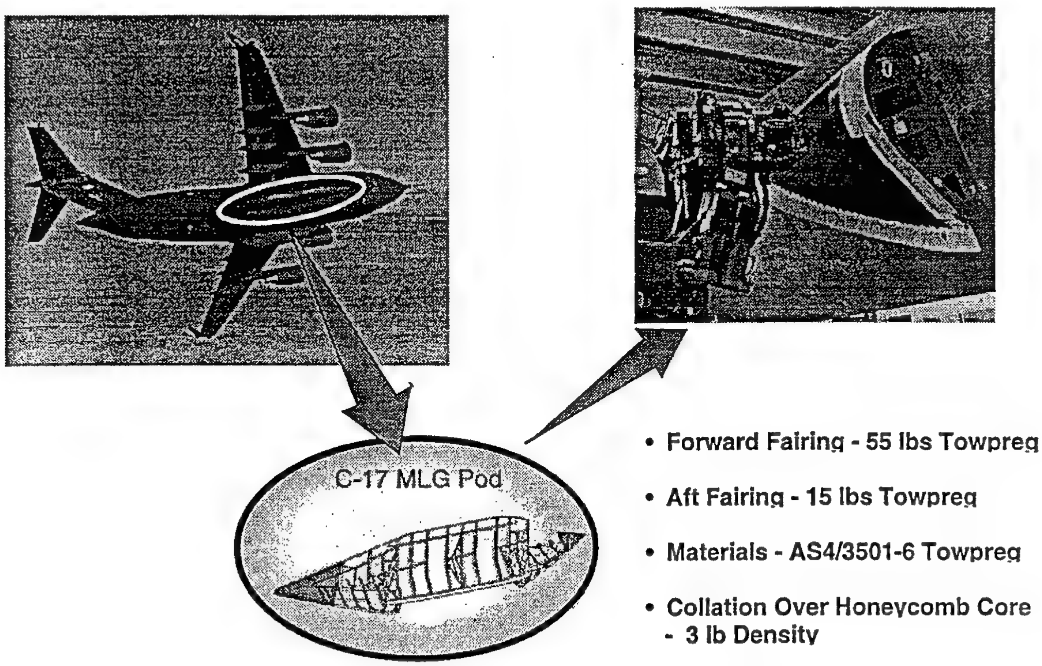


Figure 3.2-6 - Production Fiber Placement Facility Fabricating C-17 Landing Gear Pod

The push for more affordable composite parts does not stop with this development. Fiber placement alone does not solve the cost of the tooling and processes associated with the autoclave cure. The next steps in this development will be to develop methods for curing the resins as they are fiber placed. This will require a technological breakthrough, since in-situ fiber placement still requires keeping the resin warm for a considerable period of time in order to both achieve cure and to minimize the residual stresses that lead to warped parts. However, research continues to explore a number of methods to provide more complex composite parts outside of the autoclave in order to produce composite parts which will rival aluminum in cost while providing significant improvement in performance. It is believed that the need to produce more affordable composite parts will continue to push this technology toward this goal, as shown in Figure 3.2-7.

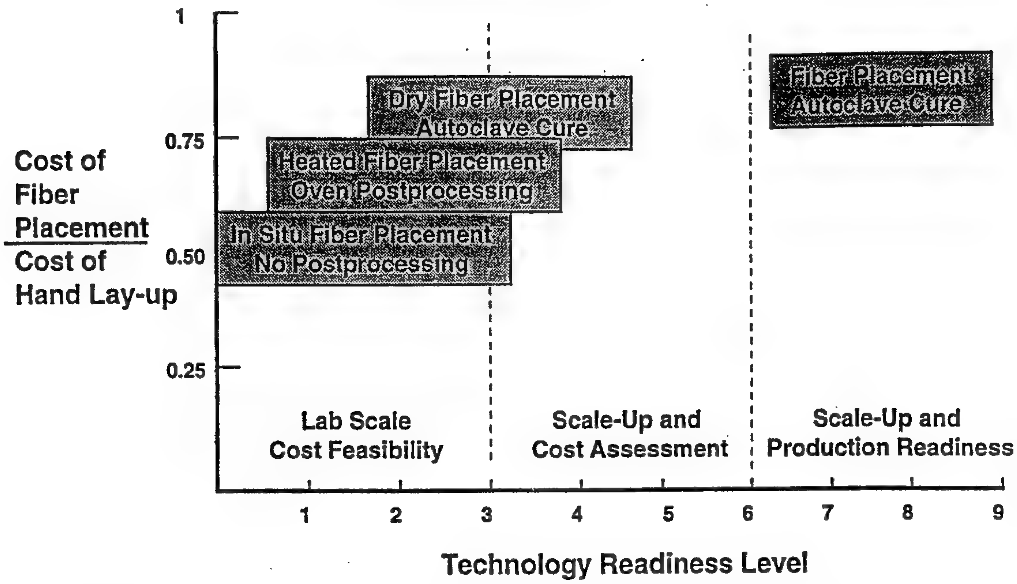


Figure 3.2-7 - The Cost Saving Potential of In Situ Fiber Placement Provides the Impetus for Research into Its Realization

4. CONCLUSIONS

There are examples of real affordability impacts that have been achieved by Science & Technology programs and initiatives. CULTURE CHANGE, Use of IPPD/IPTs, Use of METRICS, Attention to TRANSITION, and EDUCATION and TRAINING are having an impact. The greatest progress seems to occur when all these changes are attempted concurrently, but with a balance. The bottom-line is results. Those can be measured and used to continually improve. Measurement of the Value of Technologies, when technology is transitioned into production or use on a program, and the Potential Value of all S&T programs underway (or planned) will keep emphasis growing on affordability. Just-in-time learning should be made available and the development and production program customers should be involved at key steps along the way. When all S&T personnel and their customers can understand, think, speak, and act with the "language of affordability," we see real affordability results.

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TECHNOLOGY - SOLUTION FOR THE NEXT GENERATION OF AFFORDABLE STRIKE FIGHTERS

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SUMMARY

An essential element of the Joint Strike Fighter Program is the specific application of technologies to significantly reduce the life cycle cost of the weapon system. The strategy is to aggressively attack those attributes and features, which are high cost drivers for a strike fighter weapon system through various innovative approaches. The Joint Strike Fighter Program has addressed this by: 1) Identifying those specific features and characteristics which are high cost drivers so that one can apply scarce resources to the most leveraging attributes; 2) applying the Strategy-to-Task-to-Technology methodology and Quality, Function and Deployment(QFD) analysis to logically prioritize investment strategies; 3) identifying and leveraging opportunities for common technology demonstrations which apply to multiple weapon system concepts and 4) coordinating activities across the various Science and Technology(S&T) communities to target significant life cycle cost drivers for strike fighter platforms. (Key words: Joint Strike Fighter, JSF, Technology Maturation, Affordability.)

WHY THE JOINT STRIKE FIGHTER

In 1993, the Secretary of Defense, through the Bottom-Up Review process acknowledged the Services' need for an affordable solution to the aging strike fighter fleet. He also declared that the separate services solutions to this dilemma- the Navy Advanced Attack Fighter (AF/X) and the Air Force Multi-Role Fighter (MRF) programs were unaffordable and a joint solution must be found. Thus in Jan. 1994 the Joint Advanced Strike Technology (JAST) program was formally chartered to pursue advanced technology applications for future strike weapons systems. To further complicate the technology challenges facing JAST, Congress legislated in FY1995 the merging of the Defense Advanced Research Projects Agency (DARPA) Advanced Short Take-Off and Vertical Landing (ASTOVL) program with the JAST program. Just prior to entering the Concept Demonstration Program, the JAST Program was renamed to the Joint Strike Fighter (JSF) Program to reflect transition from a technology to a weapon system development program. In May 1996, the JAST Program was designated a major acquisition program.

ACQUISITION REFORMS

Numerous studies and commissions have been chartered to examine methods to improve the acquisition process. The 1986 Packard Commission highlighted areas that have become the foundation for the way the JSF program conducts its business. Key to a number of those recommendations is the focused application of technologies to achieve affordable solutions:

- Get the warfighters and technologist together to enable leveraging cost-performance trades.
- Apply technology to lower cost of the systems, not just to increase performance.
- Adequately mature technology prior to the start of engineering and manufacturing development (E&MD).

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

- Ensure that the solutions are joint.

- Instigate and catalogue acquisition reform.

Another key to ensuring proper application of scarce resources to leveraging technologies is the application of the strategy-to-task-to-technology (S-T-T) process supported by Quality, Function, and Deployment (QFD) analysis (figure 1). The STT, a top-down process, maps the relationships between the joint strike warfighting objectives, operational tasks, weapon system attributes and technology needs

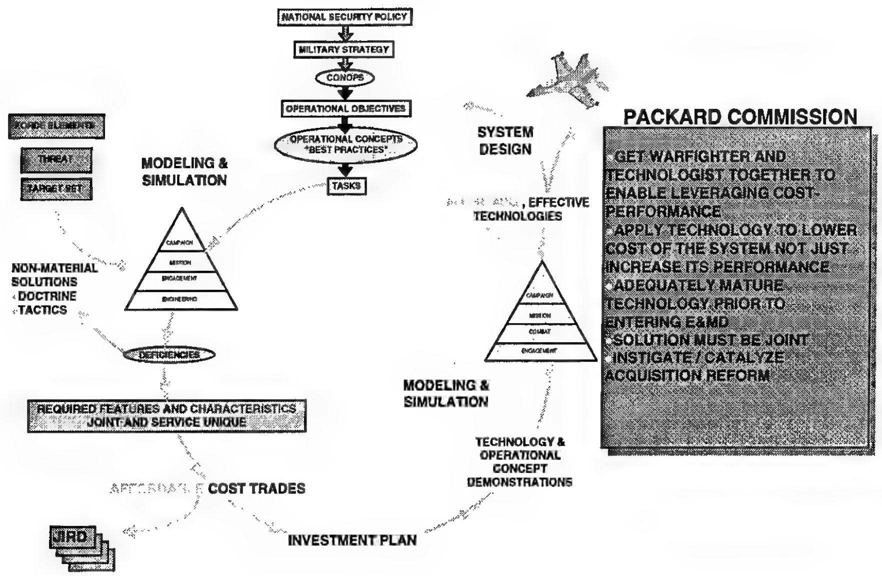

Figure 1 Strategy-to-task-to-technology process

In addition, the STT process quantifies the relative strength of the above relationships so as to identify: leveraging operational objectives and tasks; key weapon system attributes; leveraging technology areas and potential future trade areas. The JSF STT analysis established explicit linkage between the strike "warfighter" needs and technology needs. The JSF Program Office then employed the Quality, Function, Deployment (QFD), a McDonnell Douglas Corporation developed analytical tool, for prioritizing potential solutions to the services' needs. QFD is a multivariant analysis technique to aid in the decision making process. It also provides a method of bookkeeping ideas, definitions and evaluations of relationships between desires and suggested solutions. It also provides a means of auditing the progress toward a set of solutions and method for determining why a potential solution is preferred. The STT analysis in combination with the QFD flowdown provides products at every level, which aid the program in prioritizing and formulating technology maturation strategies. By using these tools you provide a technology investment "stack-up" regarding their relative contributions to affordability- the balance between sustained operational effectiveness and reduced life cycle cost.

An important tool for assisting the JSF technology investment strategy is the weapon system Life Cycle Cost (LCC) components chart (figure 2) which identifies which elements of LCC contribute the largest

percentage to the total life cycle cost. The LCC components represent recent historical data on the F-22, B-2, F-15E, and the F/A-18 C/D, E/F.

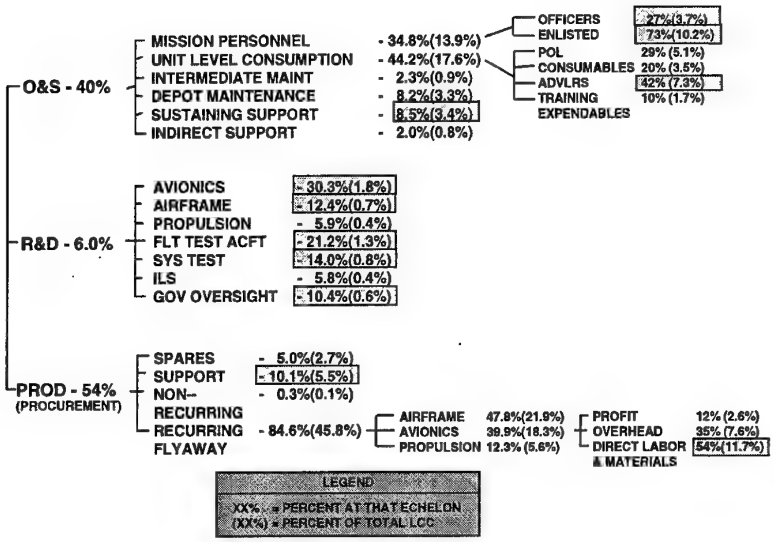

Figure 2 Historical Fighter Aircraft Life Cycle "Components"

Recent development /production programs have been characterized by low procurement quantities and rates, stealth technology and increased technical sophistication. The combination has resulted in the procurement costs representing 58% of the total weapon system LCC, with Research and Development costs rising to 15% and Operations and Support representing the remaining 27%. Armed with this information, the JSF program has targeted its scare resources at those areas/components which are very leveraging for reducing the overall Life Cycle Cost of the weapon system and not chase those technologies which did not show a major contribution to reducing the services' cost of ownership.

TECHNOLOGY MATURATION

The JSF technology maturation process is based on identifying high-leveraging technology initiatives and associated demonstrations, which meet the following criteria:

1. The technology must clearly have the potential of reducing the cost of ownership for a future strike fighter system and be targeted at a principal life cycle element. Savings goals must be established and a credible path for documenting those savings must exist.

2. The JSF program is not in the business to develop technology but build on existing technologies. The program goal is to mature those leveraging technologies through additional demonstrations such that it may be transitioned to E&MD at low risk.

3. Commonality and modularity provides significant savings when attempting to meet all the services needs and needs to be addressed up front in the design process. Also, todays' manufacturing capabilities provide significant cost savings through cost commonality.

4. Technologies not yet mature enough to make the low risk entry into E&MD, yet have the potential to significantly reduce cost of ownership, may be candidates for future upgrades to JSF and will be addressed in the overall architecture of the weapon system.

The maturation process consists of appropriate demonstrations to validate the functional, performance, and LCC impacts of the selected technologies. The process occurs at the component, subsystem, and system level through modeling, simulations, ground and flying testbeds and concept demonstration aircraft. The following is a synopsis of a select number of the technical maturation projects which offer the potential to significantly lower the cost of ownership of the next generation strike fighter weapon system.

Structures, Materials and Manufacturing:

Advanced Lightweight Aircraft Fuselage Structure (ALAFS)

This project is focused on identifying and developing concepts, methods and procedures that will facilitate much greater structural integration of both composites and metallics. Traditionally, aircraft design practices are based on the use and application of metallic and monolithic materials with the resulting design being composed of a large number of sub-components and sub-assemblies which then must be fastened together to form larger airframe structure. This is a multiyear project involved in taking the F/A-18E/F center fuselage-wing section and conducting a "clean sheet" design effort exploring new methodologies to significantly reduce part count, structural weight and life cycle costs and minimize fatigue and corrosion potential. The overall goals of the program are to demonstrate a 30% reduction in cost, 20% reduction in weights, which translates into approximately a 6-8% reduction in cost of ownership.

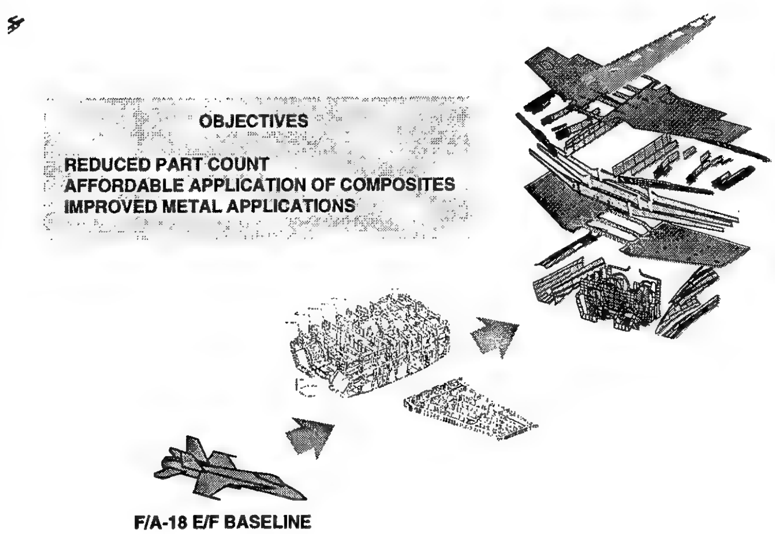

Figure 3 Advanced Lightweight Aircraft Fuselage Structure (ALAFS)

Composite Affordability Initiative (CAI)

CAI is a joint government-industry initiative focused on improving affordability through the increased use of composites in aircraft design. This initiative is composed of three components: A "fast track" demonstration, a technology transition component, and a pervasive technology effort. The fast track effort is targeted to demonstrate composite design and manufacturing concepts that offer break through in both cost and weight by increasing the structural fraction of composites in fighter airframes. The

demonstrations will consist of both a ground structural demonstration and a flying demonstrator. The technology transition component is focused on demonstrating and transitioning high risk, high payoff "proprietary" composite solutions into the competing JSF designs. The pervasive technology efforts address common composite affordability issues facing the Industry. It focuses on maturing composite designs, materials, tools, processes and assembly technologies essential to implementing significant advances in composite applications.

Lean Manufacturing

JSF is leveraging the work coming out of the Lean Aircraft Initiative sponsored by AF Wright Laboratory, Industry and academia. The initiative is focused on research which will lead to fundamental changes to the way the aircraft defense industry manufactures weapon systems. Products of this initiative will include best manufacturing practices, techniques for employing just-in-time inventory, manufacturing tools which significantly reduce variability and early identification of improved manufacturing processes. The overall goal is to convert the US aerospace industry into a "lean enterprise" the way of the automobile industry.

Manufacturing Tools

The JSF program is evaluating and funding a number of demonstrations of various "virtual" manufacturing initiatives, which show promise in addressing affordability. Virtual design, manufacturing, assembly and checkout provide a synthetic environment to evaluate producibility, production capacity, risks and insertion of new technologies and processes at a relatively modest investment. Reduction in cost of design, increased production flexibility, reduced inventory and reduced recurring product costs are potential benefits from application of these tools.

JSF Integrated Subsystems Technology (J/IST)

The J/IST program is focused on demonstrating the feasibility and affordability of an integrated suite of subsystems to dramatically lower the weight, parts count, and improve efficiency of the current-technology subsystems. The specific subsystem technology areas are the aircraft electrical systems, auxiliary power, cooling, hydraulics, flight control actuators and other aircraft utility functions. The expected LCC savings of J/IST are projected to be 4% relative to an F-22 like subsystem technologies and up to 12% relative to F-16. The two principle components of the integrated subsystems concepts are the airframe-mounted Thermal/Energy Management Module (T/EMM) and an engine-mounted Switched Reluctance Starter/Generator (SRS/G). The T/EMM is a single turbomachine, which provides centralized control and management of secondary power and thermal cooling for the aircraft. The SRS/G is an electrical device, which can function either as a motor or generator. Together these to subsystems replace the central hydraulics system, airframe-mounted accessory drive (AMAD), environmental control system (ECS), and the auxiliary power unit/ emergency power unit (APU/EPU). The technologies involved in J/IST allow an aircraft designer to replace 13 current technology subsystems with 5, resulting in less space, weight, power, cost, etc. Figure 4 illustrates this point between the traditional subsystem approach and what the JAST program is pursuing.

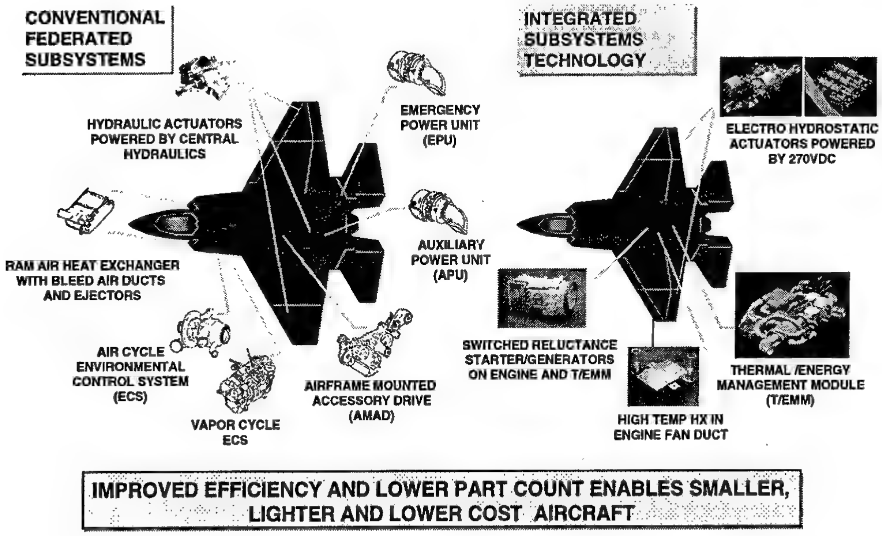

Figure 4 Comparison of Current vice J/IST subsystem Approach

Mission Systems

After surveying the Science and Technology areas for leveraging opportunities, further refining the candidates through the quality-function-deployment tool and receiving feedback from Industry and government experts in the field, the conclusions were to focus the demonstrations into four areas: Integrated core processing, integrated Radio Frequency (RF) sensors, integrated electrical optical/infrared sensors and weapons integration (figure 5). The following is a discussing of a few of the critical aspects of the mission systems focus areas. Integrated core processing is necessary to support an "open" systems architecture, which in turn allows for more affordable upgrades and significant growth opportunities. This demonstration program addresses critical technologies and software processes to support a single-crew aircraft in an information rich environment. The integrated RF sensor demonstrations are focused at reducing the risk of developing a low cost, lightweight multifunction nose aperture. Current weapon systems illustrate that an entire RF system can represent up to 59% of the avionics flyaway costs with a multifunction nose aperture at 19%. The overall demonstration objectives are to yield from 9-17% LCC savings when compared to an F-22 technology base.

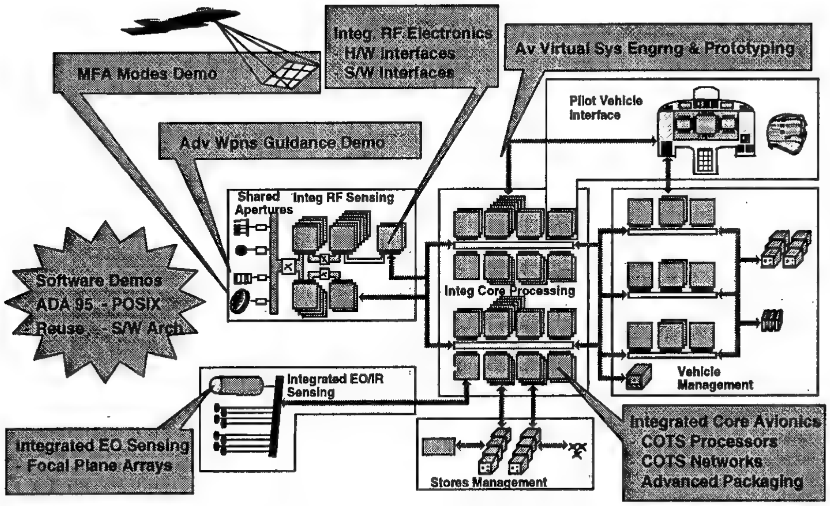

Figure 5 Mission Systems Integrated Technology Demonstrations

Propulsion Technology

The propulsion technology maturation program is focused on technologies which improve single engine safety, reliability and maintainability, survivability and affordability. Multi-service application is also a significant technology driver. An aggressive Prognostics and Health Management program is being explored for the propulsion system to maximize single engine safety and significant reduce its operations and support costs. Alternate component material solutions and manufacturing initiatives are under study to reduce procurement costs. Increases to reliability and maintainability are being pursued to reduce the propulsion system's logistics footprint and increase the sortie generation rate for the aircraft. Both ground and flying demonstrations are being performed to mature such critical technologies as: Advanced diagnostics, turbine supercooling, advanced composite materials, subsystem integration and affordable low observable applications.

Prognostics and Health Management

The prognostics and health management (P&HM) focus on the Joint Strike Fighter Program is to develop a set of fully integrated sensors and predictors, utilizing both on-board and off-board systems, which estimate life usage and can forecast potential critical failures (figure 6). This is extremely important for a single engine aircraft and can significantly reduce the number of unnecessary inspections and equipment removals. In addition, a robust P&HM architecture will support an "autonomic" logistics approach. Through autonomic logistics, the aircraft P&HM system can stimulate the aircraft systems prior to return to base and data link all anomalies to the support organizations. A reliable P&HM system can allow for prepositioning of tools and equipment and maintenance rehearsal thereby improving the sortie generation capability.

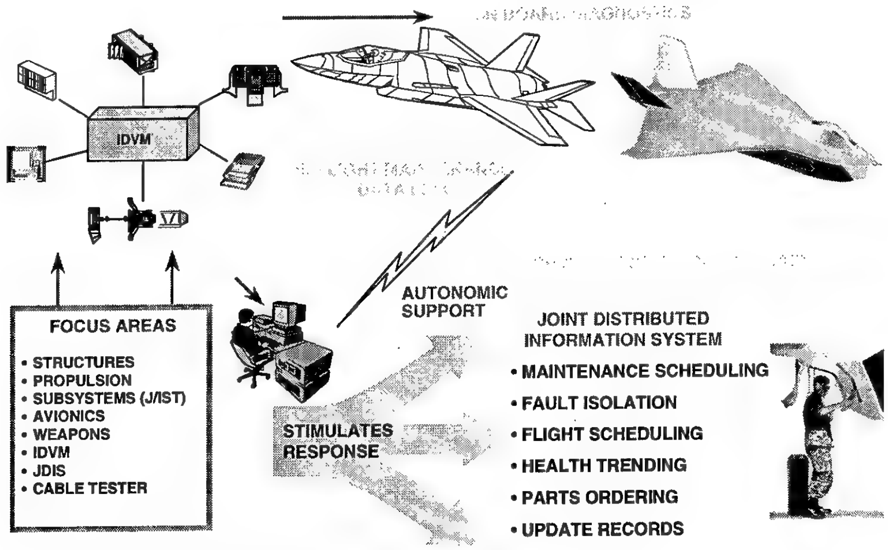

Figure 6 Prognostics and Health Management Approach

JSF Technology Impact to Affordability

Both government and industry studies have identified leveraging technology efforts, which could significantly lower the production cost (30% savings) of the Joint Strike Fighter as well as the cost of ownership (28%-32% savings). The Joint Strike Fighter Program office has focused its scarce resources in pursuing those technologies, which significantly impact the affordability of the weapon system, and provides best value to the warfighters. By knowing which of the weapon system attributes drive cost of ownership, you can get the most leverage from your investments. The Joint Strike Fighter Program is the model for affordable weapon systems of the future!

La réorganisation de la Délégation générale pour l'armement (DGA) en France

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Préambule

Comme cela est évoqué dans la présentation générale, un des objectifs de notre symposium est de traiter les perspectives gouvernementales concernant la gestion des programmes pour atteindre des coûts réalistes, ou encore permettre la mise en commun des meilleures pratiques pour relever le défi des coûts.

Le texte qui suit n'est pas une présentation exhaustive, officielle, de la nouvelle Délégation générale pour l'armement (DGA) en France. Il reflète en revanche, dans l'esprit même de notre symposium, l'analyse, par un membre de la commission FVP travaillant à la DGA, des atouts que se donne l'agence française grâce à sa réorganisation ou simultanément à celle-ci.

Ne sont donc traitées ici, sans souci d'exhaustivité, que des évolutions en rapport direct avec le thème du symposium.

Introduction

Une vaste réorganisation du système de défense a été engagée en France en 1996. Elle concerne en premier lieu les forces armées qui seront formées de professionnels et de volontaires après la suppression du service national obligatoire. L'effectif global diminuera.

Elle concerne aussi la conduite des programmes d'équipements dans tout ce qui détermine les coûts, dates de livraison et performances des matériels fournis aux armées : les objectifs fixés, de 1997 à 2002, sont de réduire de 30 % les coûts des programmes d'armement et le coût d'intervention de la DGA elle-même.

Ces objectifs s'intègrent dans le cadre d'une « politique d'armement » qui peut se décliner en quatre grands axes :
- la coopération internationale,
- l'organisation de l'industrie, en premier lieu en Europe,
- les relations entre administrations clientes et industriels fournisseurs,
- les méthodes de management des programmes.

Nous nous proposons de les évoquer successivement, en nous attardant évidemment sur la quatrième.

1 La coopération

En France, les programmes menés en coopération, principalement mais pas exclusivement avec l'Allemagne, l'Italie et le Royaume Uni, comptent pour environ 15% du budget. Ce pourcentage fera plus que doubler d'ici 2002. La réduction des coûts passe alors par les grandes options suivantes :

-le renoncement aux duplications inutiles d'un pays à l'autre...ce qui ne veut pas dire que des complémentarités ne peuvent pas être utiles au sein de l'OTAN,

-l'optimisation globale des spécifications de matériel retenues, par opposition à une trop complexe addition des besoins recensés,

-l'homogénéisation des procédures entre pays, voire l'unification, partiellement au moins, comme en ouvre la possibilité l'OCCAR, organisme conjoint pour la coopération dans le domaine de l'armement en Europe.

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

L'expérience, c'est une évidence dans le domaine de l'aéronautique, montre qu'on a rarement trop de persévérance et de résolution pour réussir les recettes connues :
- planification et prospective,
- partage des financements,
- standardisation des matériels,
- effet de la concurrence.

2 L'organisation industrielle

Les regroupements réalisés ou envisagés aux Etats-Unis concourent à la constitution de groupes de potentiel considérable. Sommairement, la situation française apparaît différenciée selon les secteurs et les enjeux sont multiples.

2.1 Les avions de combat sont réalisés par Dassault Aviation, qui produit aussi des avions d'affaires, et les hélicoptères et avions de transport civils et militaires par Aérospatiale, dans le cadre de coopérations bien connues : Eurocopter, Airbus, ATR...Un premier enjeu est celui du rapprochement de Aérospatiale et Dassault Aviation pour constituer un pôle aéronautique couvrant l'ensemble des applications civiles et militaires, comme cela se fait, par exemple, au Royaume Uni ou en Allemagne.

2.2 Plusieurs sociétés françaises ou à très forte participation française, complémentaires ou concurrentes entre elles selon les activités, produisent des équipements ou systèmes électroniques de défense. Un deuxième grand enjeu est celui du rapprochement de certaines de ces sociétés pour constituer un pôle électronique.

2.3 La perspective de création de ces pôles a soulevé et soulève encore en France des discussions qui pourraient être évoquées lors de nos débats. Il semble entendu que la construction d'avions ne se conçoit désormais, hors quelques niches, qu'à l'échelle mondiale ; pourraient ainsi apparaître et subsister, à terme, un grand constructeur américain et un autre regroupant les champions de chaque pays européen. La concurrence entre européens dans le domaine des avions finirait ainsi par disparaître. Pour les autres domaines, en revanche, par exemple les missiles, les satellites, les radars etc., existent encore manifestement des concurrences en Europe. D'où la question de savoir, s'agissant ici du management stratégique des coûts, s'il vaut mieux des regroupements conduisant à terme à un unique grand leader européen, en concurrence avec son ou ses homologues américains, ou au contraire le maintien d'une saine concurrence entre européens lorsque c'est possible. Corollairement, le rapprochement d'un avionneur et d'un électronicien, par intégration verticale, est-il favorable ou à craindre ?

2.4 La création de l'Organisation pour la recherche et la technologie appelle une ouverture, une extension des domaines traités par l'AGARD à l'ensembles des applications, et c'est bien naturel. Apparaissent alors, en France, un troisième et un quatrième enjeux. D'une part les armements terrestres, dont le champion en France est GIAT-Industries, réalisateur du char Leclerc. D'autre part la construction navale militaire, confiée en France à DCN qui fait partie de la DGA: la réforme engagée a cependant clairement défini le périmètre de son activité, purement industrielle, et son mode de gestion, analogue à celui d'une entreprise. Les conditions dans lesquelles ces secteurs à vocation par essence militaire pourront faire face aux contraintes du temps sont autant de défis. Pour ce qui nous préoccupe ici, il ne faut pas perdre de vue que ces industriels ne sont pas seulement des fabricants de blindés ou

de coques de navires, mais surtout des intégrateurs de systèmes de combat.

2.5 A ce stade, il est intéressant d'observer que les coopérations multinationales sur les programmes d'une part, et les restructurations industrielles transnationales d'autre part, toutes deux sources d'économies pour les armées concernées, ont jusqu'à présent rarement été conjointes. Lorsqu'un programme en coopération est décidé, chaque pays participant souhaite maintenir, voire créer, dans ce cadre, des capacités industrielles ad-hoc : c'est très précisément le contraire d'une restructuration ! D'une certaine façon, le prix à payer pour constituer de grands programmes en coopération, ce qui est en soi vital sans qu'il soit besoin de le justifier ici, est souvent de freiner de possibles restructurations transnationales.

3 Relations entre administration cliente et industriel fournisseur

3.1 Concurrence et responsabilisation

L'idée maîtresse des relations administration/industrie est double : faire jouer la concurrence et responsabiliser l'industriel ; responsabiliser d'autant plus le maître d'œuvre industriel qu'il a été mis en concurrence.

Lorsque pour un système les maîtres d'œuvre possibles auront été mis en concurrence, le gagnant aura la responsabilité et la liberté de choisir ses équipementiers. En revanche, face à un maître d'œuvre en situation de monopole en Europe, il faut plus de transparence, de contrôle des prix et de négociation d'objectif de productivité. La concurrence devra alors jouer au niveau des sous-systèmes et équipements.

Il va de soi que les standards civils doivent être la règle à chaque fois que c'est possible et que l'interchangeabilité ou l'interopérabilité au sein de l'Alliance doivent être assurées du mieux possible.

3.2 Des contrats forfaitaires

Développement et production doivent être considérés ensemble et faire l'objet d'un contrat couvrant développement, industrialisation et une première livraison de matériel. La règle est d'avoir des contrats forfaitaires, à prix fermes ou, pour certains contrats de longue durée, ajustables sur un indice de prix représentatif.

4 Management des programmes

4.1 Des équipes intégrées pluridisciplinaires

La logique séquentielle selon laquelle un état-major exprime un besoin qu'un architecte transforme en spécifications pour lesquelles un industriel propose des solutions techniques est proscrite.

Pour chaque programme, un directeur de programme se voit mettre à disposition les spécialistes et experts des différentes filières relevant du domaine de la gestion (achats, expertise des coûts, finance...) ou de la technique (spécialités techniques, logistique...). Est ainsi constituée, au sein de la DGA, une direction de programme qui est associée à l'officier de programme concerné, et en tant que de besoin à l'industriel, pour former une équipe intégrée. C'est cette équipe qui se voit notifier des objectifs de coûts, délais, qualité, disponibilité opérationnelle...

4.2 Des architectes de systèmes de force

La préparation de l'avenir a été revue. Des systèmes de forces correspondant à de grandes fonctions opérationnelles ont été définis . Un collège d'architectes de systèmes de forces assure la cohérence entre ces systèmes et entre les systèmes d'armes au sein des systèmes de force. Les architectes établissent un plan prospectif à

trente ans, préparent les programmes jusqu'au moment où le relais est pris par un directeur de programme au sein d'un service de programmes. Huit systèmes de force ont été définis :
- dissuasion,
- commandement-conduite-communication-renseignement,
- mobilité stratégique et tactique,
- frappe dans la profondeur,
- maîtrise du milieu aéroterrestre,
- maîtrise du milieu aéromaritime,
- maîtrise du milieu aérospatial,
- préparation et maintien de la capacité opérationnelle.

Au sein des états-majors, des officiers de concept opérationnel sont désignés pour être les interlocuteurs naturels des architectes de systèmes de force.

4.3 Une nouvelle organisation

La DGA a été profondément réorganisée, passant d'une structure essentiellement par domaines ou milieux à une structure par type d'activité, métier ou fonction.

4.3.1 Trois directions traitent de la préparation et de la conduite des programmes :

- La direction des systèmes de force et de la prospective (DSP), pour la recherche, les développements technologiques et la préparation de tous les programmes. Elle a aussi la responsabilité des programmes de missiles stratégiques, d'observation, de télécommunications, d'information.
- La direction des systèmes d'armes (DSA), responsable de la réalisation des programmes navals, terrestre, aéronautiques et de missiles tactiques.
- La direction des programmes, méthodes d'acquisition et de la qualité (DPM), qui regroupe les compétences nécessaires : achats, qualité, maintien en condition opérationnelle etc. Une partie centrale définit et coordonne la politique générale ; ses autres membres sont mis à disposition dans les autres directions pour mettre en œuvre cette politique sous la conduite de responsables opérationnels, directeurs de programmes en premier lieu.

Ces trois directions oeuvrent en effet dans le cadre d'une organisation matricielle ; des entités relevant de domaines de la technique ou de la gestion regroupent les spécialistes nécessaires, et les mettent, qu'il s'agisse de compétences fonctionnelles ou techniques, à la disposition des services ou des directions de programme.

4.3.2 Trois directions ou service de la DGA ont des activités d'industriel ou de prestataire de service :

- La direction des centres d'expertises et d'essais (DCE) regroupe tous les centres techniques et d'essais de la DGA ; ceux-ci ont des relations contractuelles avec leurs clients au sein de l'administration ou à l'extérieur, en France ou à l'étranger.
- La direction des constructions navales (DCN) d'une part, le service de la maintenance aéronautique (SMA) d'autre part exercent des activités industrielles clairement séparées des activités étatiques.

4.3.3 Deux directions sont chargées des actions, d'une part de politique industrielle et de coopération internationale, et d'autre part des exportations d'armement :

- La direction de la coopération et des affaires industrielles (DCI),
- La direction des relations internationales (DRI)

4.3.4 Enfin deux autres directions sont chargées des ressources humaines (DRH), de la gestion et de l'organisation (DGO).

En tout, la DGA est forte de 47000 personnes, dont 12000 dans les centres techniques et d'essais, plus de 21000 dans la DCN et 3500 dans le service de la maintenance aéronautique.

5 Mise en œuvre des principes

En pratique, pour ce qui relève de notre sujet aujourd'hui, les évolutions les plus significatives sont les suivantes.

5.1 Etudes amont

Auparavant, les personnes en charge d'un domaine technique ou opérationnel de base proposaient de conduire des études amont, soit avec des industriels, soit directement par exemple dans des laboratoires universitaires. Ils considéraient bien sur les débouchés possibles, en relation avec les états-majors, mais sans être toujours orientés par une expression de besoin final précise. Les mêmes responsables proposaient au départ les études puis se voyaient confier la responsabilité de les faire réaliser. Une procédure montante, procédait par étapes successives pour retenir, écarter, ou modifier les projets, jusqu'à l'approbation, globalement, par le ministre de la défense. Enfin l'évaluation était essentiellement interne.

Désormais, les études sont orientées selon une procédure descendante, les différentes responsabilités d'orientation, de prescription, de réalisation et d'évaluation étant clairement identifiées.

5.1.1 Le Service d'architecture des systèmes de forces (SASF), qui élabore un plan prospectif à trente ans en relation avec les états-majors, et le Centre des hautes études de l'armement (CHEAr), qui conduit des réflexions stratégiques et économiques, orientent les études amont en définissant leurs objectifs. Ces mêmes organismes conduisent in fine l'évaluation a posteriori associée.

5.1.2 Le Service de la recherche et des études amont (SREA), à partir de ces objectifs, des différentes contraintes, notamment financières, et des options possibles, incluant la coopération internationale, élabore la planification des études à réaliser et confie la réalisation de chacune à l'un des directeurs de programme d'études amont répartis dans les différents services de programmes.

5.1.3 Ce directeur de programme d'études amont les fait réaliser et assume la responsabilité de tous les choix à effectuer, mais il doit rendre compte au prescripteur, avant et pendant les travaux, de façon à garantir la cohérence entre ce qui est commandé au titulaire et la planification d'ensemble. En règle générale, et c'est une nouveauté, la DGA ne confiera directement d'études qu'aux entreprises industrielles, dont la vocation est de participer aux programmes d'armement, à charge pour elles d'une part de participer au financement et d'autre part de rechercher la coopération de laboratoires de recherche pour aboutir aux objectifs fixés.

5.1.4 L'évaluation se fait par un processus remontant, depuis les directeurs d'études amont, qui élaborent des documents d'évaluation et de politique technique dans leur domaine, jusqu'au CHEAr et au SASF.

5.2 Lancement et conduite des programmes

La sélectivité et la cohérence avec lesquelles les programmes seront lancés sont accrues. Une phase systématique de conception à coût objectif est conduite en examinant les réponses possibles au besoin : rénovation ou évolution d'un équipement existant, achat sur étagère, développement d'un nouveau matériel. C'est un des rôles des architectes de systèmes de force. Puis des coûts objectifs explicites sont notifiés aux directeurs de programme ; ceux-ci ne sont donc pas

juges et parties dans les arbitrages initiaux de leur programme.
Un portefeuille de réductions de coût possibles est tenu à jour et le directeur de programme doit se rapprocher le plus possible de l'objectif, en travaillant en équipe intégrée, comme cela a déjà été évoqué. In fine, mieux vaut un coût objectif ambitieux que l'on peut ne pas atteindre compte tenu du grand nombre d'aléas associés, qu'un coût objectif trop important, facile à atteindre, et qui ne génère finalement aucune économie...alors même que le programme se déroule conformément aux prévisions.
En cours d'exécution, les architectes s'assurent que le programme se déroule de façon satisfaisante, et peuvent le cas échéant appeler des évolutions.

5.3 Centres d'expertise et d'essais

Auparavant, chaque grande direction de milieu disposait en son sein des centres d'essais essentiels correspondants : par exemple le centre d'essais en vol (CEV), le centre d'essais des propulseurs (CEPr) ou le centre d'essais aéronautiques de Toulouse (CEAT) dépendaient de la direction des constructions aéronautiques qui avait en charge la conduite des programmes aéronautiques. Un directeur commun , chargé du « milieu » aéronautique, avait autorité pour décider des priorités et des contraintes à tenir dans les essais, et pour préparer les programmes d'investissement de ces établissements.
Inéluctablement, la priorité étant donnée à la réussite des programmes par grand milieu (air, mer, terre, missiles-espace), des duplications de moyens ou de compétences ont de facto été acceptées.
Désormais, tous ces centres sont regroupés au sein de la même direction et une procédure unifiée d'examen des investissements et des domaines d'intervention exclut toute duplication inutile. Les services de programme notifient à ces centres des contrats (pour être précis, en 1997, ce ne sont pas toujours juridiquement de véritables contrats si les deux parties sont financées à partir de la même ressource budgétaire) . Ici encore, un prescripteur décide ce qu'un autre responsable doit réaliser.

5.4 Activités industrielles

Le même constat est immédiat pour les activités industrielles de la DCN : alors qu'auparavant le directeur chargé de la conduite des programmes navals était aussi chargé d'une grande partie de leur production, ces responsabilités sont maintenant clairement dissociées.

6 <u>Conclusion</u>

La réforme de la DGA, entérinée dans des textes fondateurs depuis le début de 1997, devrait, compte tenu de son ampleur et des objectifs d'efficacité assignés, nécessiter deux années pour être accomplie. D'ores et déjà, de nombreux indicateurs de résultats permettent d'apprécier les économies obtenues ou escomptées sur les différents programmes d'armement ou opérations comparables. Des exemples clairs mettent déjà en évidence les retombées bénéfiques que peuvent produire la détermination à mettre en œuvre des méthodes variées d'optimisation dans lesquelles les coûts sont systématiquement pris en considération. Il est loisible d'imaginer, une fois considéré le management stratégique des coûts lors du présent symposium, de consacrer des séances futures à des comparaisons homogènes sur des programmes et des contenus physiques précisément définis.

cost reduction 2002/1997 - 30 %

- COOPERATION
- EUROPEAN DEFENCE INDUSTRY
- COMPETITION
- PROGRAMS MANAGEMENT

COOPERATION

- JOINT PROGRAMS:
- 15 % of the budget in 1997
- 34 % in 2002
- From self-interest without industrial restructuring........
- To integrated european programs

EUROPEAN DEFENCE INDUSTRY

- IN FRANCE
- Aerospatiale+Dassault=aircraft pôle
- Electronics pôle
- Heavy engineering pôle (GIAT, DCN)
- ...
- on the way for multinational groupings

COMPETITION

- applied to prime contractors responsible for their choice of equipment manufacturers
- OR
- to sub-systems and equipment
- FOR
- fixed price contracts

MANAGEMENT (1/3)

- Program directorates and Integrated project teams
- WITH
- Ambitious targets for costs, delays, quality, and operational readiness...

MANAGEMENT ([illegible])

- 8 forces systems corresponding to
- 8 major operational functions:
- deterrence,
- intelligence,
- mobility and support,
- air/land combat
- etc. ....WITH

MANAGEMENT ([illegible])

- 8 forces system architects:
- ensuring compatibility between weapons systems
- planning and monitoring the programs, with the armed forces

DGA ORGANIZATION ([illegible])

- 3 directorates for programs :
-
- Forces systems & prospective (DSP)
- Weapon systems (DSA)
- Programs management, acquisition methods and quality control (DPM)

DGA ORGANIZATION ([illegible])

- 2 directorates &1 service for industrial activity, service providing:
-
- Survey and trials centres (DCE)
- Shipbuilding (DCN)
- Aeronautic maintenance (SMA)

DGA ORGANIZATION ([illegible])

- 4 directorates:
- Cooperation and industrial business(DCI)
- International relations(DRI)
- Management and organization(DGO)
- Human ressources(DRH)

DGA ORGANIZATION ([illegible])

- DGA= 47 000 persons
- including
- 21 000 in shipbuilding
- 12 000 in survey and trials centers
- 3 500 in aeronautic maintenance

- overall optimization
- 1) of businesses, know-hows, activities and working modes
- 2) of forces systems
- VS
- almost separate air, sea, or land optimizations

- Research and up-stream studies:
-
- 1)Top-down oriented process
- 2)With industrial companies
- VS
- Bottom-up, including direct labs funding

- Programs management:
-
- 1)preparation by a forces system team...specifying targets to the integrated project team
- 2)permanent cost reduction management

- reform of operation and working modes of DGA, in order to reduce by 30 % it's own running cost.

Reorganisation of Evaluation and Research to Support Future Defence Procurement

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SUMMARY

In response to the changing defence environment and political and economic pressures, UK non-nuclear defence science and technology capability has been drawn together as the Defence Evaluation and Research Agency (DERA). The agency remains a government organisation but operates as a trading agency supplying its services to customers (principally in the UK MoD) on a full cost basis, and required to demonstrate best commercial practices and financial viability. This paper traces the early days as the Defence Research Agency (DRA) through to its current structure, highlighting some of the challenges along the way, and sets out some future initiatives to maintain its position.

1 INTRODUCTION

As a result of the political drive in the UK to make government departments more efficient and more accountable, and in the light of the changing defence environment following the reduction in the threat from the Eastern Bloc, a strategic decision was made to create the Defence Research Agency (DRA). This agency was to comprise all non-nuclear defence research activity carried out by government establishments in the UK. The UK armed services would manage the government funding which had previously been voted direct to the research establishments, with the new agency acting as a supplier charging on a full cost basis. Subsequently the DRA was joined by other government organisations supplying science based services to the MOD to form an enlarged agency. This paper traces the history of what is now the Defence Evaluation and Research Agency (DERA), charting the key factors and decisions that shaped the agency along the way.

2 BACKGROUND

Like most large Western nations with substantial defence commitments, the UK had developed a large defence research organisation covering sea, land, air and command and control systems. The capabilities were distributed over a number of establishments, although over the years there had already been some rationalisation which had concentrated capability into a number of key establishments (Figure 1).

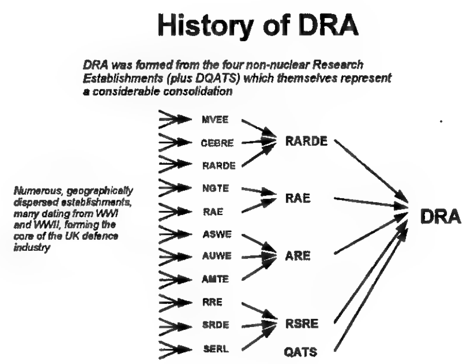

Figure 1 - History of DRA

These establishments were distributed across the country on a number of key sites (Figure 2).

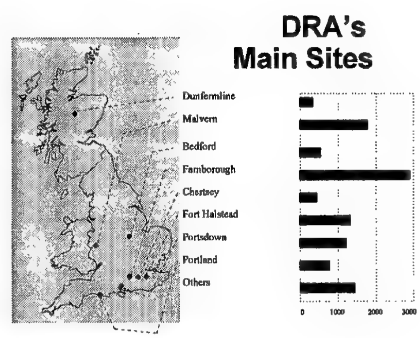

Figure 2 - DRA's Main Sites

Although a coherent policy on the aims of defence research did not exist, the main thrusts were generally acknowledged to be:

- To provide the UK Ministry of Defence with an intelligent customer status.
- To carry out critical long term research that would not be commercially attractive to industry.
- To ensure that future technology was available and suitably protected in sensitive or secure areas.

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

- To transfer technology to UK industry to develop and produce advanced defence systems for the UK armed forces.

Despite a general understanding of these principles, there was insufficient control of the process by the ultimate customers and plenty of scope for research establishments to carry out research that interested them rather than what was needed. Lack of control could become an even greater problem as budgets were successively cut and it was important that scarce resources were concentrated in the right areas.

3 THE CHALLENGE

Once the decision to create the DRA had been made in 1988 an ambitious target was set to bring the agency into existence on 1 April 1991, with full trading status from April 1993. To achieve this target, the DRA Implementation Team was created drawing staff from all parts of the existing organisation and from the UK MOD under the leadership of a two star civilian from MOD. Some of the key questions this team had to consider were:

- Who are the customers and how should research funds be disaggregated to them?
- What should the contractual arrangements be bearing in mind that the agency would still be owned by the government?
- Could the new agency be financially viable on a commercial basis?
- How would the agency be viewed by partners in international collaborative agreements?
- What freedoms should the agency have in setting employment terms and conditions?
- What degree of competition should be allowed with industry?
- How would the necessary culture change in the agency and in its customers be created?
- What performance targets and indicators were appropriate?

- I will now address some of these questions to illustrate the shape of the agency emerged:

4 CUSTOMERS

It was quickly established that Defence Research could be divided into three principal categories:

Strategic Research - or "blue skies" - looking at technologies in a timeframe greater than 15 years. This accounted for about 7% of the total research budget and was high risk. The appropriate customer was identified as the Chief Scientific Adviser within the UK MOD.

Applied Research - this accounted for 65% of the research budget and was directly in support of medium and short term operational requirements where a staff target or staff requirement existed. The appropriate customer was identified as Deputy Chief Defence Systems within the UK MOD. Individual research packages were managed by the OR branches, supported by scientific specialists. A total of 60 packages was set up based on capability (eg air defence, strike warfare, sea surface warfare) rather than technologies. A further subdivision was made to create seven technology packages for those areas of technology which served all future capabilities eg sensors, materials etc.

Project Support - this accounted for about 20% of the research budget and was directly in support of existing procurements, technology demonstrators and imminent procurement decisions. The appropriate customers were the project offices in MOD Procurement Executive (PE).

OGD and Commercial - this accounted for about 8% of the research budget for non MoD customers.

5 CONTRACTUAL RELATIONSHIP, DISAGGREGATION OF FUNDS AND COMPETITION

The status of the agency was a very sensitive issue and the way forward was seen to be to set up a framework document that defined its methods of working and relationships with important stakeholders.

Because both the agency and its principal customers (defined above) were owned by the UK Secretary of State for Defence who could not contract with himself, a legal contract was not possible. However the relationship was established so that to all intents and purposes a proper contractual relationship existed. Customers defined their requirements, the agency responded with a defined package of work priced on the basis of full economic costs, and the customer would then negotiate a contract with deliverables and milestones on a fixed price or ascertained costs basis. The original funding that had been given direct to the research establishments was disaggregated to the customers after the individual research areas first made their own assessment of where their work should sit in the research packages, and then agreed these with the customers. Full blooded competition with industry was at first considered, but it was agreed that the agency was in an advantageous position with its privileged knowledge of the requirements of another part of its own organisation, and also its own knowledge of industry gained through its involvement in collaborative research and advice to MOD in procurement competitions. Full competition would also inhibit the free flow of technology into industry - a key factor in enabling

industry to develop the products that our armed services need.

6 INTERNATIONAL COLLABORATION

This area was expected to be the most difficult to manage and a failure to take our international partners along with us would have probably been a fatal blow to the agency initiative. However, as it turned out this did not present the problems we expected. The preservation of our status as a government agency, and the relationship with the armed services and industry convinced our partners that our aims and values had not changed and they quickly gave us the signal to proceed with the reforms.

7 CULTURE

All the fine words about the creation of agencies, changes in the name of the organisation, and changes to our structure would come to nothing if the majority of staff did not embrace the changes and modify their ways of working, attitudes and beliefs - in short we needed a complete change in culture. This was seen to be the greatest challenge we faced - and I have to admit that we have not achieved it yet. The key attitudes we wanted to engender were :

- Customer Care
- Cost Efficiency
- Total Quality

Although these seem obvious to those in the commercial world, they are not embedded in the culture of a government organisation. There is no "bottom line" of financial viability that drives people to be efficient and recognise that satisfied customers are the key to survival. The introduction of new processes, restructuring of our departments, more freedoms to reward and promote our staff on the basis of their performance, the introduction of management training has started to promote the cultural shift we need, but it is recognised that this is a very long term process.

8 PERFORMANCE TARGETS

The setting of performance targets was required by government so that the benefits of agency status could be objectively measured and demonstrated to the public. It was seen within the agency as a key element in bringing about the cultural change we were seeking, and the means by which we could develop the agency. However, it is not easy to have objective performance measures in the field of research and a great deal of effort was put into selecting the right measures.

Efficiency - the key efficiency measures were related to manpower utilisation and asset utilisation. This allowed us to judge how much of our valuable engineers and scientists time was spent actually doing research and our ratio of direct to indirect staff. Asset utilisation - return on capital employed - is a standard commercial ratio which allows us to judge whether our assets are usefully employed and not just costing us money in the hope that one day somebody will come along to use them.

Financial - standard commercial discipline to cover costs by income and produce a surplus to reinvest and pay off start-up loans from HM treasury.

Quality - delivery of the products to time, improvements in customer satisfaction.

Management Systems - the introduction of management accounting, information systems, project management processes and human resource systems to support the delivery of products to the customers.

Following vesting day on 1 April 1991, the DRA was given two years to carry out "shadow" trading before going fully onto a trading fund on 1 April 1993. During this first year, another significant change was made when the existing Chief Executive was replaced by a new man recruited from industry. The DRA team had done an excellent job in establishing the structures and processes necessary to operate as a trading agency. Most of what they set up is still in existence today - a tribute to their foresight and energy. However, different talents are needed at different stages of a reorganisation and it was now time to bring commercial experience into the organisation to instil the discipline and working practices which are second nature in industry. This move certainly proved to be a watershed in the style and pace of management. This was also a time of defence cutbacks and these early years saw a realignment of research as some areas prospered under the new freedoms whilst others found the going very difficult indeed. The emphasis was now on convincing the customers that funding your pet research project would provide important future defence capability.

An examination of the business soon revealed that the organisation possessed a lot of underutilised major assets and the ratio of support staff to revenue earners (the skilled scientists and engineers) was too high. This made it impossible to meet efficiency targets which were considered normal in industry. A major programme of rationalisation of assets and a reduction in support staff was embarked upon. A good example was the rationalisation of flying activities. Before the creation of the agency, the DRA had operational airfields at Bedford and Farnborough but the level of activity was low on both sites. A major airfield existed also at A&AEE Boscombe Down (not then part of the agency) and, following open competition, Boscombe Down won the contract to carry out all research flying allowing the airfields at Bedford and Farnborough to be closed to

research flying (although they still exist to support commercial light aircraft operators). At the same time, a major rationalisation of the airfleet took place reducing the total number of aircraft from over 100 in 1991 to 65 in 1993 to 43 today as shown in Figure 3.

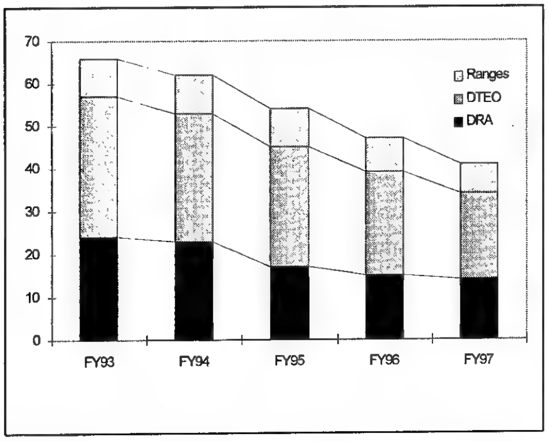

Figure 3 - Rationalisation of Aircraft Fleet

In 1993, the UK government launched a major initiative to examine the cost of defence through a series of Defence Cost Studies. DCS4 considered the provision of science based services to the MOD, with special reference to the experience in the DRA. DCS4 concluded that the DRA model could be applied to many of these other services and a decision was made to create the larger Defence Evaluation and Research Agency (DERA). This was not only a major leap forward in the size of the agency, but it also changed the nature of the organisation and expanded its customer base. The DERA now comprised four distinct groups:

DRA - the existing DRA organisation with its major customers in the central MOD.

DTEO - the Defence Test and Evaluation Organisation comprising test ranges and the former A&AEE Boscombe Down. This was largely a facilities based organisation as opposed to the manpower based DRA. The major customers were the MOD PE Project offices and armed services.

PLSD - Protection and Life Sciences Division comprising Chemical and Biological Warfare protection and human factors research.

CDA - Centre for Defence Analysis comprising Operational Analysis organisations covering strategic studies, wargaming and operational effectiveness studies. Customers ranged from PE to central policymakers.

The component parts are shown in Figure 4.

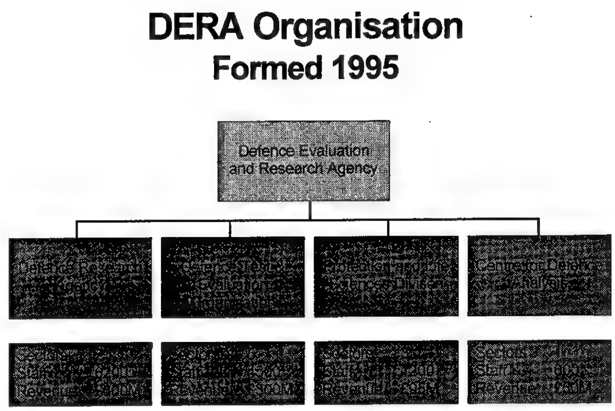

Figure 4 - DERA Organisation

There is a marked difference in the relative sizes - in both manpower and commercial terms - but this was less important than forming divisions that had common characteristics and a degree of synergy and would therefore have similar problems to solve in the transformation. This new organisation was given far less time to settle in - From the announcement in autumn 1994, full trading was to begin on 1 April 1995. The transformation was successfully achieved and trading began on the due date. As with the DRA, the discipline of trading and satisfying customers soon revealed those facilities that were important to the end user and there were successes and failures along the way. The integration of the new parts of DERA was expected to take some considerable time - indeed DTEO (my own organisation) launched a programme of organisational and cultural change labelled DTEO 2000 with the expectation that the four divisions would be in existence until the turn of the century. As it turned out, the integration (or at least the critical functions of financial management, meeting customer requirements and a commitment to change) proceeded much more quickly than anticipated. There were a number of reasons for this; many of the new organisations already had quite good mechanisms for tasking by customers and project management (which had already proved necessary in a high cost, safety conscious environment), the experience of the DRA could be quickly brought to bear on the new organisations, and staff already had some idea of what the effects of agency were through their contacts with the staff in DRA. Much work was being done on cultural change, largely stemming from the DTEO 2000 initiative, so that a mission, vision and values were being defined (Figures 5 and 6).

DERA MISSION

to harness science and technology to UK defence needs.

DERA VISION

to be recognised as the world's foremost defence science and technology organisation and thus be a source of pride to our owners, our customers and our staff.

Figure 5 - DERA Mission and Vision Statements

Values

- **Impartiability & Integrity**
  Acting in a way that is right even if this may appear to bring disadvantage to DERA or its customers, and on no account compromising acceptable standards of probity or safety.
- **Openness & Honesty**
  Acting in a straightforward and fair manner to encourage confidence and trust.
- **Customers**
  Providing responsive and efficient services that satisfy customers.
- **Excellence**
  Achieving the highest professional and technical standards.
- **Innovation**
  Being imaginative and flexible in our work with a zest to exploit opportunities.
- **Teamwork**
  Pulling together to realise our full potential.
- **People**
  Recognising individuals' needs, aspirations and achievements.
- **Suppliers**
  Developing relationships that add value for MOD and benefit wealth creation in the UK.

Figure 6 - DERA Values

These were seen to be important in an organisation which was aiming to sweep away the constraints and mindset of the previous civil service culture by introducing flatter management structures, matrix management and a reduction in the regulations and paperwork that were endemic under the old system. Our CE has a favourite story about his experience on one of his first visits

"Quite early on in my tenure of office I was visiting one of my establishments on the South Coast. Like much of my widely dispersed estate it had a neglected look to it - post war utilitarian design rendered bleak and untidy through penny pinching maintenance. Inside a depleted staff struggled to keep up with the many demands put upon them. I was talking to them about the need for change. One of the local managers responded by giving me a sheet of paper to illustrate the problems he faced. It was a purchase requisition form. On the back it had the signatures of the various officials whose concurrence was required. There were 13 signatures on the back. A few had signed it more than once because they had requested more information on first receipt. As I looked through the progress of the transaction as recorded by the signatures one could immediately see why all this scrutiny was necessary.

Was there adequate financial provision?
Was the purchase to be subject to competition?
Were our standard contract terms applied?
Were security conditions satisfied?

And so on. Everyone had their job, and each job was obviously useful. Then I turned the piece of paper to discover what was being purchased. It was £485 of software. The point the local manager was demonstrating was that while the rationale for each part of what he was required to do could easily be explained, the process as a whole made no sense at all."

From the mission, vision and values a set of critical success factors were identified. These are shown at Figure 7.

DERA Critical Success Factors

- We need customer recognition of the value of DERA's output
- We must have recognised world class science and technical capabilities
- We need motivated competent people
- We must have 'value added' partnerships with industry
- We must have resilience to provide our customers with reasonable security of supply
- We must have business excellence in a single cohesive organisation.
- We must have unimpeachable probity
- We must have global outlook
- We need to be a national asset with international standing

Figure 7 - DERA Critical Success Factors

In light of this, and the success of the reorganisation in integrating the new divisions, another major reorganisation was initiated, just two years after the second! It was realised that the organisation now had two imperatives for future success:

Individual sectors had demonstrated their ability to run their own businesses, but now needed to draw on other sectors throughout DERA (not just in their own divisions) to offer the best DERA solutions to meet customer needs.

Senior management should concentrate their efforts on developing strategic policies and programmes to develop the organisation's future direction and ensure its survival.

As a result, DERA was reorganised on 1 April 1997 as shown in Figure 8.

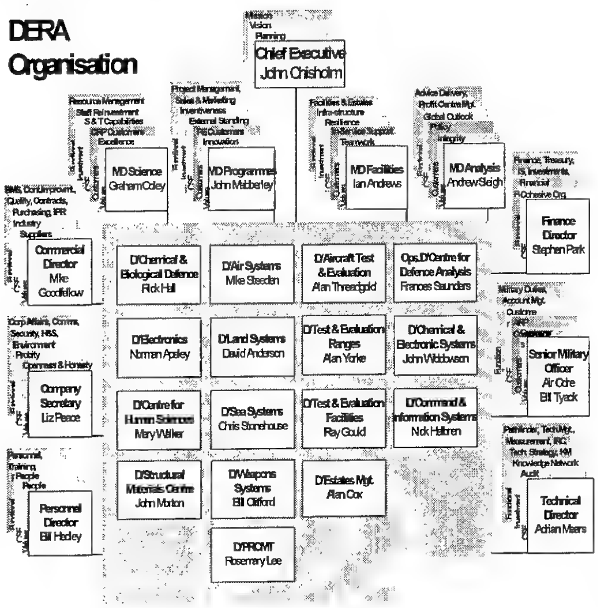

Figure 8 - DERA Organisation

The Managing Directors no longer retain an operational responsibility for the performance of their old divisions, but they have been given key responsibilities that span the whole of DERA. As an example, the MD for DTEO now has responsibility for developing our facilities across the whole of DERA, bringing into his remit wind tunnels, radar systems and other facilities to join the ranges, aircraft and test facilities he used to control.

So much for management, reorganisation and culture that go with any major change in organisations. What about the results? Are we serving the ultimate customers - the procurement organisation, the armed services and the taxpayer - better now than we did before? Judgements are inevitably subjective - and perhaps some of our performance indicators such as ROCE and profit are not the most appropriate for a technical audience. However, I should like to present a few statistics that will illustrate how the organisation has changed and perhaps celebrate its survival as a viable organisation in the face of severe budget cuts.

Let us go back to where DERA fits in to the overall MOD picture. Figure 9 illustrates how DERA supports the MOD throughout the equipment life cycle.

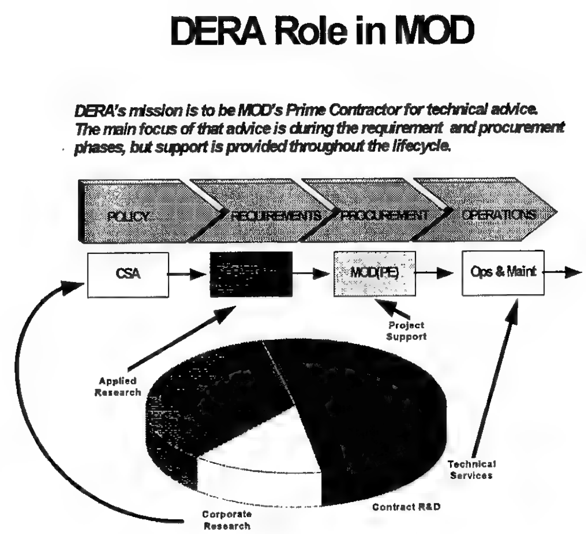

Figure 9 - DERA's Role in MOD

Times have been hard in the defence world - but Figure 10 shows how we have maintained our scientific output as measured by direct manhours despite funding cuts approaching 40%.

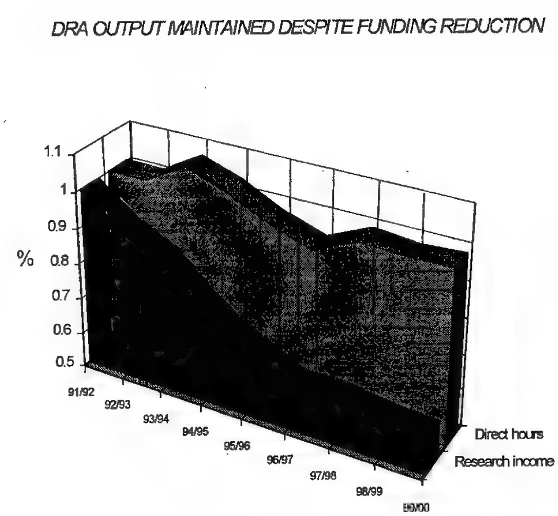

Figure 10 - Output

This has largely been achieved by increasing our employment of scientists and engineers at the expense of support staff (Figure 11), and a reduction in the cost of support services from £220M in 1992/3 to less than £100M today.

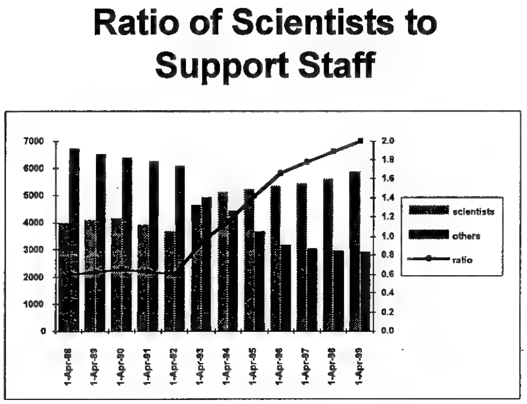

Figure 11 - Ration of Scientists to Support Staff

Returning to some of the original challenges we faced we are now confident that DERA is in sound financial health, operates profitably, has a strong balance sheet and adequate cash in hand. Most of our activities are competitively priced, well managed, competently marketed and if necessary could survive in a 'free market'. Our relations with principal customers are very good and many of the old constraints of public organisations and the associated culture are changing. This is no time however, to sit back and congratulate ourselves and imagine that the job is done. The environment is constantly changing, presenting new threats and opportunities. Figure 12 illustrates the cycle of change and development we have embarked upon; we have reached the 'piggy bank' where we have established our viability, got industry on side and we are paying back dividends to HM Treasury.

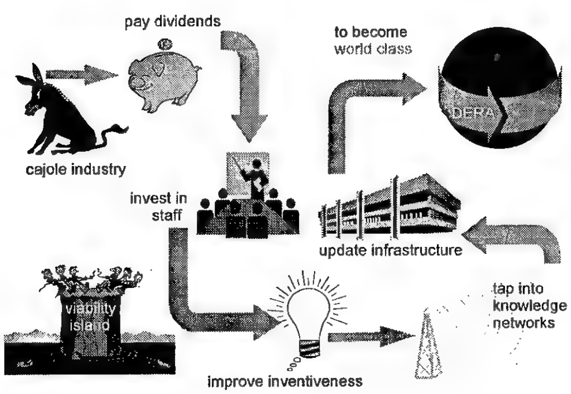

Figure 12 - Cycle of change and development

For the future, backed by our new organisational structure, we are engaged in 14 initiatives. I will focus on four of these - staff reinvestment (Figure 13), Inventiveness (Figure 14), Knowledge networking (Figure 15) and Investment (Figure 16).

Staff Reinvestment

Investment	
Utilisation	0.2%
Running costs	£45 million
Capital	£0 million

- Resource management
- Career mapping and development training
- Professional training
- Professional management
- Proactive recruitment

Figure 13 - Staff Investment

Inventiveness

Investment	
Utilisation	1.0%
Running costs	£55 million
Capital	£25 million

- Problem
- Danger of conservatism in our work
- Proposal
- Mechansims to allow local discretion to support innovative investment in creative teams
- Encourage customers to ask for work to be done on a fixed and firm price basis
- Harness less costly techniques such as computer simulation as an element in a total trials programme
- DERA capital investment can be used as a stimulant to kick-start advanced programmes

Figure 14 - Inventiveness

Knowledge Networking

Investment	
Utilisation	0.6%
Running costs	£27.6 million
Capital	£8.3 million

- Problem
- Growing propensity to insularity
- Proposal
- Enhancing measurement of knowledge networking through the Technical Assessment process, including assessment of the advantage gained from International Collaboration
- Investing in the development and maintenance of a suite of Information Systems and database tools
- Embarking on a project to change to culture to be more outward looking
- Creation of a virtual laboratory infrastructure to support world-wide collaboration
- Investing in the Knowledge Visualisation Centre to develop data mining and visualisation techniques
- Providing a more coherent approach to academic research

Figure 15 - Knowledge Networking

Investment

Investment	
Capital	£104 million

- Problem
  - rationalisation programme addressed the non-viable aspects of our physical infrastructure - now we need to bring the remainder up to an equivalent standard
- Proposal
  - strategic plans are being drawn up for each of our sites
  - £74 million investment at Porton Down
  - investment is being planned at Malven, Fort Halstead and Boscombe Down to enable them to function as 'core' sites
  - the requirements of many DTEO ranges are to be assessed for action to bring them to a habitable and economic standard
  - medium scale sites such as Beford, Chertset, Aquila, Defford and Farnborgough Queen's Gate will be reviewed for investment or consolidation

Figure 16 - Investment

It is by initiatives such as these that we aim to develop and maintain DERA as a world class organisation and fulfil our mission and vision.

Cost Reduction Strategies in Acquiring Aircraft Weapon Systems at "Pax River"

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1.0 SUMMARY

The most significant consolidation in the U.S. Department of Defense (DoD) just occurred at the Naval Air Station in Patuxent River, Maryland. This air station is commonly referred to as "Pax River." The U.S. Navy collocated its aircraft program managers, developers, testers, procurement, and logistics personnel at Pax River to achieve greater efficiency and effectiveness in buying aircraft weapon systems. The purpose of this paper is to discuss this consolidation and the tremendous research, development, test and evaluation (RDT&E) capability now resident at this site.

2.0 BACKGROUND

Challenge

The challenge to the U.S. Navy in the early 1990's was to substantially downsize the work force, reduce the number of support sites, and retain sufficient capability to support the Fleet in response to new national defense priorities.

Approach

In 1989, the total number of Navy civilians across the U.S. associated with the acquisition and support of naval aviation systems totaled 52,000 people. The Navy's end strength goal for 1999 is 28,000 people. This represents a 46 percent reduction in work force. In 1989, the total number of shore station sites was 18 including headquarters and field activities. The Navy's goal for 1999 is to have 8 sites in operation. This represents a 55 percent reduction in shore station sites.

In addition to the downsizing and consolidating more functions at fewer sites, the Navy also reorganized its entire Naval Aviation acquisition corps around a new organizational structure and concept of operations to improve the efficiency of the acquisition process.

Consolidation at Pax River

Since 1943, the Pax River complex has served as the Navy's principal aircraft test and evaluation facility. From 1945 until 1992, the complex was known as the Naval Air Test Center. Due to actions taken as a result of a nationwide Base Realignment and Closure (BRAC) process during fiscal years FY91, FY93, and FY95, Pax River is now a full spectrum acquisition activity. BRAC 91 and 93 broadened the mission of Pax River by moving 1,700 aircraft research and development positions from Warminster, Pennsylvania, and 250 propulsion positions from Trenton, New Jersey, to Pax River. The consolidation brought with it new engineering facilities and the collocation of engineering expertise across a broad spectrum of technical disciplines.

With the relocation of 2,800 positions from the Naval Air Systems Command and Program Executive Offices (PEO's) as a result of BRAC 95, Pax River has become the site of a $16 billion dollar acquisition arm of the U.S. Navy. Pax River is unique within DoD in that air combat system acquisition program managers are now collocated with their principal aircraft RDT&E support personnel. See Figure 1.

Acquisition Organization

The U.S. Navy's current organization for acquiring aircraft weapon systems for the Fleet is shown in Figure 2. The Chief of Naval Operations (CNO) establishes the operational requirements for the Fleet. The

Paper presented at the AGARD FVP Symposium on "Strategic Management of the Cost Problem of Future Weapon Systems", held in Drammen, Norway, 22-25 September, 1997, and published in CP-602.

Assistant Secretary of the Navy for Research, Development and Acquisition (ASN (RD&A)) serves as the Navy's acquisition executive and satisfies those operational requirements with material when required.

The ASN (RD&A) is supported by aircraft PEO's. There is a PEO for tactical aircraft programs (PEO(T)), one for the cruise missile project and unmanned aerial vehicles (UAV's) joint program (PEO (CU)), and one for air antisubmarine warfare (ASW), assault aircraft and special mission programs (PEO(A)). The PEO's oversee individual aircraft acquisition program managers called Program Managers Air (PMA's). The PMA's are responsible for cost, schedule, and performance of their acquisition programs as well as their life cycle support. For example, the F/A-18 PMA, who works for PEO(T), is responsible for all of the upgrades to the F/A-18 in inventory and the ongoing development and support of a new tactical aircraft called the F/A-18 E/F.

PMA's typically have small offices and rely on the Naval Air Systems Command (NAVAIR) to man their acquisition teams. NAVAIR supports the program manager by providing contracting officers, lawyers, engineers, test and evaluation, logistics, industrial, and corporate operations personnel to these teams. Team members include field activity RDT&E personnel from NAVAIR's aircraft division called the Naval Air Warfare Center Aircraft Division (NAWCAD) headquartered at Pax River and NAVAIR's weapons division called the Naval Air Warfare Center Weapons Division heardquartered at China Lake, California.

The organizational structure for NAWCAD is shown in Figure 3. NAWCAD is composed of a number of competencies including program management, contracts, logistics, research and engineering, test and evaluation, corporate operations and shore station management. Competency managers assign personnel to PMA integrated program teams to provide the necessary expertise to acquire and support aviation systems. See Figure 4.

3.0 PAX RIVER RDT&E CAPABILITY

The NAWCAD Patuxent River organization represents an enormous consolidation of engineering talent, facilities, and aircraft at one site. The NAWCAD work force is currently 11,400 employees composed of 1,300 military, 4,100 civil service, and 6,000 contractor personnel. A total of 67 scientific and engineering laboratories are at Pax River as a result of this consolidation. There are also 137 RDT&E aircraft to support the acquisition mission.

Research and Development Capability

North Engineering Center

As part of the BRAC process, Pax River received new facilities to accommodate the influx of the new technical staff and laboratories. The North Engineering Center, a new 255,000 square foot (23,690 sq m) facility, was built principally to accommodate the ASW research and development engineers who moved from Warminster, Pennsylvania. The center is approximately 65% laboratory space and accommodates over 400 personnel. The facility houses hardware integration centers and software production facilities for maritime surveillance aircraft. Within the North Engineering Center is a large acoustic sensors laboratory which is used for the development of new ASW sensors.

The North Engineering Center is located adjacent to the Force Aircraft Test Squadron (FATS) which conducts technical testing of air ASW weapon systems. The aircraft are used by both research and development and test and evaluation personnel. In addition, the operational test and evaluation squadron, VX-1, is located next to FATS which allows for the timely transition of technology from the research and development laboratory to the operational test and evaluation community due to this collocation.

South Engineering Center

The South Engineering Center, a new 450,000 square foot (41,807 sq m) facility, was built principally to accommodate the influx of air vehicle, aircrew systems, and avionics technologists from Warminster, Pennsylvania and NAVAIR headquarters. The facility houses over 800 engineers and scientists.

Within the South Engineering Center are numerous air vehicle, aircrew systems and

avionics labs. One of these is the Horizontal Accelerator (HA), a certified facility used for operational testing and evaluation of various systems in crash environments. The heart of the facility is an accelerator capable of providing controllable and repeatable time-mirrored crash pulses simulating the conditions which occur during crash on land or in water. The facility has supported tests and evaluation of rigid and energy-attenuating seats, ejection seats, clothing assemblies, restraints, and body-mounted equipment.

Materials Laboratory

The Robert N. Becker Laboratory is adjacent to the South Engineering Center. This laboratory is home to the aerospace materials division at Pax River. It consists of 23 state-of-the art laboratories. The laboratories are occupied by approximately 100 materials technologists. The extensive fabrication, processing, test and evaluation capability that exists in these laboratories supports many materials projects. These facilities provide a capability for the complete synthesis and characterization of existing and advanced materials and new materials concepts. Maritime environment simulation and characterization are emphasized.

Vertical Accelerator

The Vertical Accelerator is a newly constructed facility with the mission to test and evaluate new ejection seat technology that is being researched and developed for future defense forces. It is unique because it is the only such facility in the U.S. capable of live (human) subject testing.

The facility is useful in a variety of human factors and equipment testing, including human tolerance to ejection seat accelerations and onset rates, component structural integrity, restraint system function, physiologic compatibility cushions, lumbar pads, ballistic inertial reels, seat platform and spinal alignment, and rescue and survival kit evaluation, both structural and physiological. The facility has the capability to support medical monitoring of live subjects, high-speed and real-time photography, ordnance modifications, and data acquisition.

Microwave Test Facility

This Microwave Test Facility (MTF) is the last of the Warminster laboratories to move to Pax River. The mission of this facility is to design, develop, test and evaluate antennas, radomes and related avionics systems for fleet aircraft. The MTF includes two anechoic chambers, six outdoor antenna ranges, a plastic fabrication lab used to build radomes, and a one-of-kind Rain Erosion Test Facility to evaluate the reliability of radome designs. Some of the products produced by this facility include new antennas for aircraft programs, antenna and radome installations for global positioning system, and installation design to minimize electromagnetic interference between F/A-18 subsystems. The final product for any project is an antenna system installation ready for flight testing. The goal is to optimize performance prior to flight to reduce the overall design and flight test costs.

New Propulsion Facility

Construction of the Propulsion Systems Evaluation Facility (PSEF) began in the spring of 1996 and is slated for completion in December 1997. The PSEF will house NAWCAD's propulsion testing of engine accessories and aircraft engine systems. This includes an accessory test area, helicopter transmission test area, UAV propulsion test area, fuels and lubricants test facilities, and a rotor spin facility that will enable engineers to evaluate the rotating components of gas turbine engines. About 124 engineers and technicians will work in the one-story, 78,000 square-foot (7,246 sq m) building.

Test and Evaluation Capabilities

Air Station

The Pax River Complex is located 60 miles (97 km) south of Washington, D.C., and 90 air miles (145 km) from the Fleet in Norfolk, Virginia (Figure 5). The complex is composed of a 7,000 acre (28.3 sq km) Naval Air Station at Patuxent River, Maryland, and an 850 acre (3.4 sq km) Webster Field annex located 10 miles (16 km) away. The main all-weather sea level airfield at Pax River has three heavy capacity runways; 6,400 ft, 9,700 ft, and 11,800 ft (1,951 m, 2,957 m, and 3,597 m) long.

Eleven hangars provide over 1.2 million square feet of space (111,483 sq m).

Air Space

The Pax River Complex is located beneath a restricted air space controlled by Naval Air Station Air Operations. The restricted air space is approximately 60 miles (96 km) by 30 miles (48 km) wide. This restricted air space and the Warning Areas immediately off the East Coast provide 50,000 square miles (129,500 sq km) of air space in which to conduct flight test operations.

Naval Test Wing Atlantic

Currently, Pax River is the busiest flight test center in the world with over 20,000 hours being flown by the Naval Test Wing Atlantic, an organizational arm of the Test and Evaluation Group (Figure 3). Flight operations include activities performed by the Strike, Rotary Wing, and Force aircraft test squadrons and the U.S. Naval Test Pilot School. Strike platforms include the F/A-18, F-14, EA-6B, T- 45, and UAV's; surveillance aircraft such as the E-2C, P-3, and S-3; and rotary wing aircraft such as the V-22, SH-60B, UH-60, and CH-53 helicopters.

Test Article Preparation

The Test Article Preparation group provides aircraft instrumentation and aircraft modification services. A complete metal shop and composite shop capability allow rapid prototyping of aircraft modifications which enables proof-of-concept testing aboard RDT&E aircraft. Recent activities have included the integration of missiles aboard maritime patrol aircraft and the incorporation of guns aboard Navy helicopters.

Atlantic Ranges and Facilities

The Atlantic Ranges and Facilities Department provides both flight and ground test facilities necessary for the comprehensive evaluation of aircraft weapon systems. Significant ground and flight test facilities include the following:

Air Combat Environment Test and Evaluation Facility (ACETEF)

This facility is a fully integrated ground test facility allowing full-spectrum test and evaluation of aircraft and aircraft systems in a secure and controlled engineering environment. The facility uses state-of-the-art simulation and stimulation techniques to provide test scenarios that will reproduce actual combat conditions. Aircraft systems are deceived through a combination of simulation by digital computers and stimulation by computer-controlled environment generators that provide radio frequency, electro-optical, and laser stimuli that closely replicate real signals.

The ACETEF has a variety of individual labs that, when networked, can simulate virtually every aspect of air combat operations. Laboratories include the tactical aircraft-sized Anechoic Chamber (100 ft x 60 ft x 35 ft [31 m x 18 m x 11 m]) and a soon to be completed Large Anechoic Chamber which will be 180 ft x 180 ft x 65ft (55m x 55 m x 65 m) and will accommodate multiple tactical aircraft or the larger aircraft in inventory. Other components include the Shielded Hangar which measures 300 ft x 150 ft x 65 ft (92 m x 46 m x 20 m), and the following laboratories: Operations Control Center, Manned Flight Simulator, Aircrew System Laboratory, Electronic Warfare Integrated Systems Test Laboratory, Threat Air Defense Laboratory, Communications / Navigation / Identification Laboratory and an Offensive Sensors laboratory.

The High Performance Computing (HPC) Center is also part of the ACETEF complex. The HPC Center provides 15 gigaflops peak, 12 gigabytes memory, and 353 gigabytes total hard disk storage capability and provides the necessary processing and memory requirements to create high fidelity simulations.

Electromagnetic Environmental Effects Test and Evaluation Facilities

Pax River has leading edge electromagnetic environmental effects (E^3) research and testing capability with over 15 specialized facilities located at one site. These facilities support electromagnetic compatibility (EMC), electromagnetic vulnerability (EMV),

electromagnetic radiation (EMR), electromagnetic pulse (EMP), electrostatic discharge (ESD), precipitation static (P-Static), Lightning, communications security (COMSEC), TEMPEST, Emission Control and various hazards of electromagnetic radiation.

The EMC and EMI test facilities are the shielded hangar and anechoic chamber referred to under the ACETEF description above. These facilities provide an isolated electromagnetic environment for inter/intrasystem testing of the total aircraft

The EMP simulation facility consists of horizontal center-fed dipole and vertical monopole base-fed antennas that provide capability to perform EMP vulnerability testing on aircraft. Pulse rise time is 7 nanoseconds. Peak amplitude is greater than 50 kV/m.

The ESD facility has high voltage and high amperage generators that provide capability to test the effects of and protection from lightning strikes and nearby discharge. The E^3 team also has the ability to determine vulnerability of aircraft navigation and mission receivers due to precipitation static buildup on the aircraft skin.

Aircraft Test and Evaluation Facility (ATEF)

The ATEF provides the capability to ground test installed aircraft propulsion, mechanical, electrical, and pneumatic subsystems in a controlled environment, during static and engine operating conditions. This facility is an enclosed, acoustically designed building which can operate 24 hours per day regardless of noise or weather restrictions. The facility can be made "light tight" and provides a suitable environment for the evaluation of night vision devices.

Dynamic In-Flight Radar Cross Section Measurements

The Radar Cross Section (RCS) measurement facility conducts dynamic in-flight RCS, jammer-to-signal ratio (J/S), chaff measurements relative to aircraft, helicopters, UAV's, towed targets, and decoys. The integrated facilities provide telemetry, tracking data, range control, airborne instrumentation, and RCS data acquisition, all in a centralized workstation allowing analysis and display of the in-flight dynamic RCS measurements in real time. Data products include RCS amplitude versus aspect, Doppler power spectrum, downrange profiles, and Inverse Synthetic Aperture Radar imagery measurements.

Electronic Warfare Flight Test Facility (EWFTF)

The EWFTF is comprised of a wide variety of highly sophisticated equipment that supports the test and evaluation community. These discrete systems (made up of transmitters, receivers, tracking and slaved antenna pedestals, fixed antennas, emitter control circuitry, and computers) are configured to generate a wide variety of radar and communication radio frequency signatures in support of aircraft electronic warfare (EW) avionics test measurements. The EW facility also develops, maintains, and operates special purpose data acquisition, processing and display systems. The combination of these systems and the RF signature generators are used to support a wide variety of in-flight EW integration test measurements.

Automatic Carrier Landing Systems (ACLS) Facility

The ACLS Facility has cradle-to-grave responsibility for air traffic control and landing systems used onboard carriers, amphibious assault ships, and Marine Corps expeditionary airfields. This facility provides the ability to correlate airborne data, ground systems data, and independent tracking data for flight analysis. The facility assures that these landing systems provide safe and reliable approach and landing guidance to all shipboard and expeditionary aircraft in all weather and sea state conditions. The facility supports the development and testing of current and future systems, new and modified hardware and software, and the development of both ground and airborne control systems.

Carrier Suitability Facilities

Carrier suitability facilities include a steam catapult and arresting gear on one of the runways. Use of these facilities is necessary

to determine if new or modified equipment installed on aircraft can survive the launch and recovery cycles associated with carrier operations. Also, if the work involves a new airplane or modified engine, steam ingestion test may be in order to ensure that the engine can tolerate the steam which is vented from the catapult during launch.

Electronic Systems Flight Test Facility

The Electronic Systems Flight Test Facility provides the capability to conduct development support and test and evaluation of aircraft antennas, antenna installations, secure and nonsecure analog and digital communication and data link systems, satellite communications systems, identification friend or foe systems, navigation systems, and radar systems. The facility provides the capability for unobstructed testing in an overwater, smooth ground plane, low EMI test environment, with ground/airborne testing limited only by line-of-sight radio frequency propagation conditions.

Aircraft Stores Certification Facility

The purpose of this facility is to conduct comprehensive ground testing of aircraft/store compatibility. The facility is used in the evaluation of armament/stores management systems, suspension and release equipment, interface with loading and ship installation equipment, internal gun installations and external gun pods, targets, and verification of technical manuals.

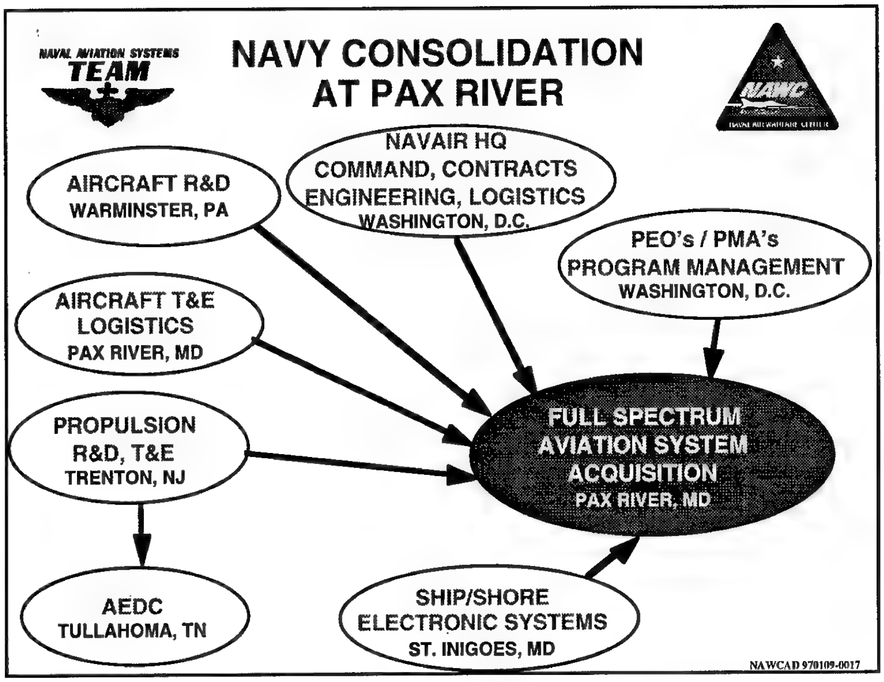
The firing tunnel is one of seven component laboratories associated with this facility. The laboratory includes two enclosed concrete structures 300 ft long, 40 ft wide and 25 ft high (91 m x 12 m x 8 m), which are used for internal and external firing tests. Measurements are made of muzzle velocity, cyclic rate of gun fire, projectile dispersion, boresight retention, boresight adjustment procedures, gun gas concentration and gun bay temperatures. Evaluation of ammunition feed and spent brass ejection systems are also conducted.

4.0 CONCLUSION

This consolidation at Pax River has created the most integrated acquisition and RDT&E work force in the world for aircraft weapon systems. Coupled with a reorganization, this consolidation has significantly reduced the work force; reduced facility infrastructure costs; and effectively collocated personnel, facilities, and aircraft at one site.

As the 21st century unfolds, The U.S. Navy is poised to buy weapons for warriors more effectively and efficiently than ever before.

In addition, Pax River RDT&E infrastructure can serve the needs of government and commercial entities interested in developing, testing, and demonstrating aviation products for a world market.



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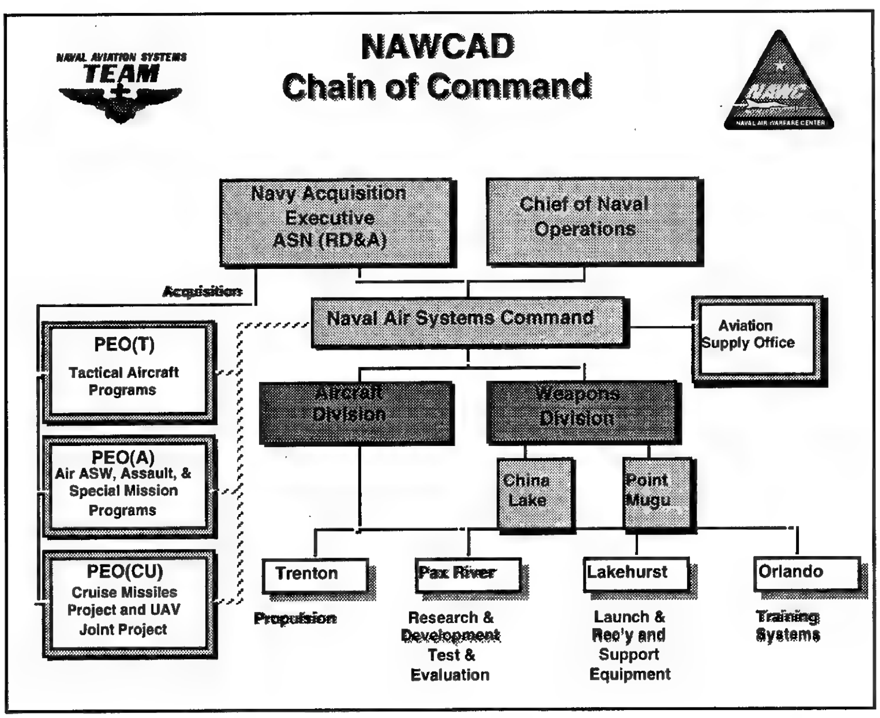

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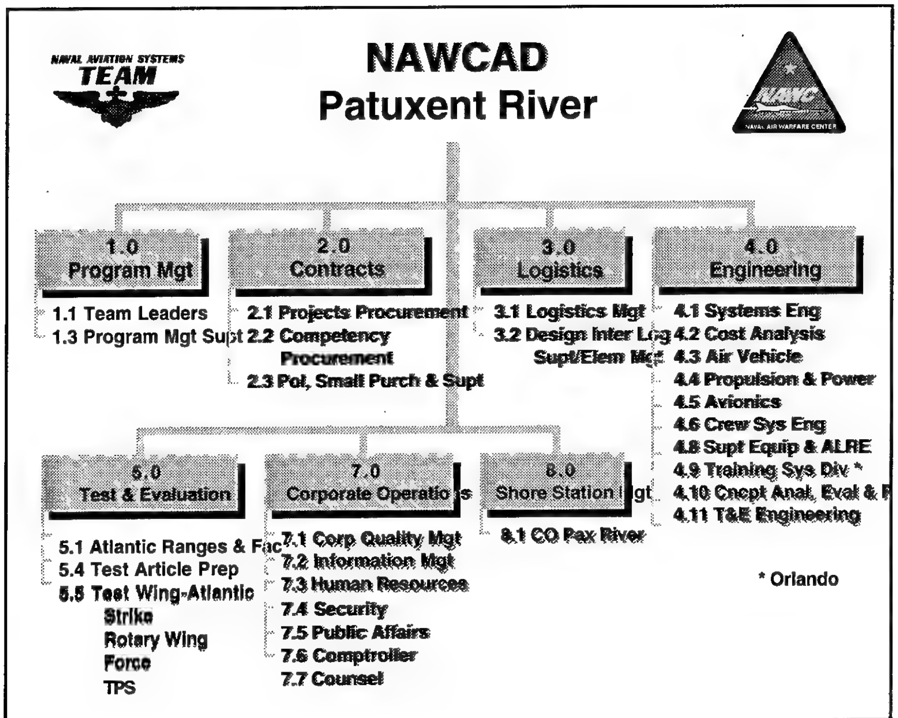

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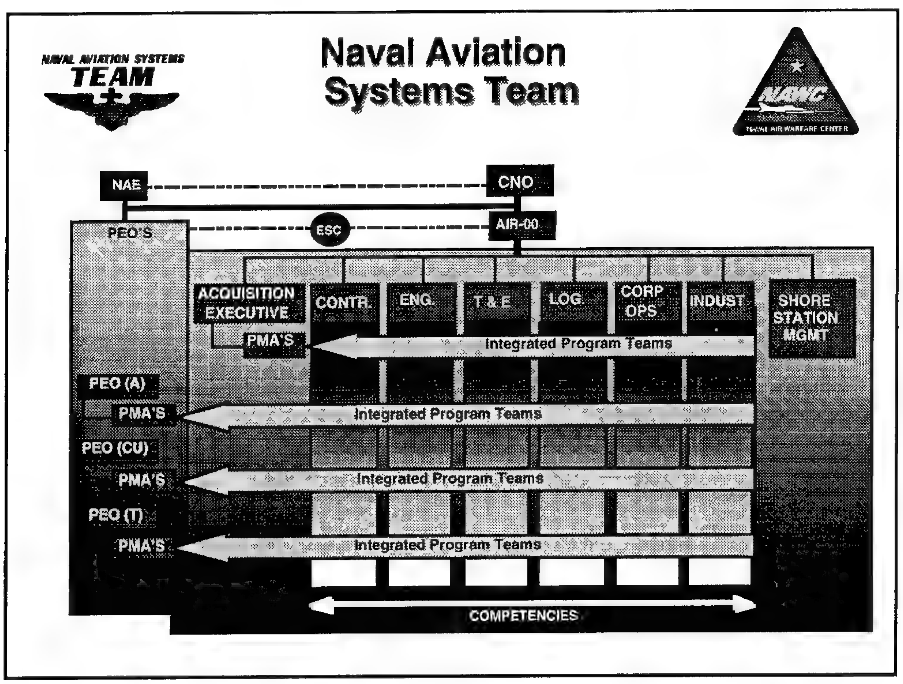

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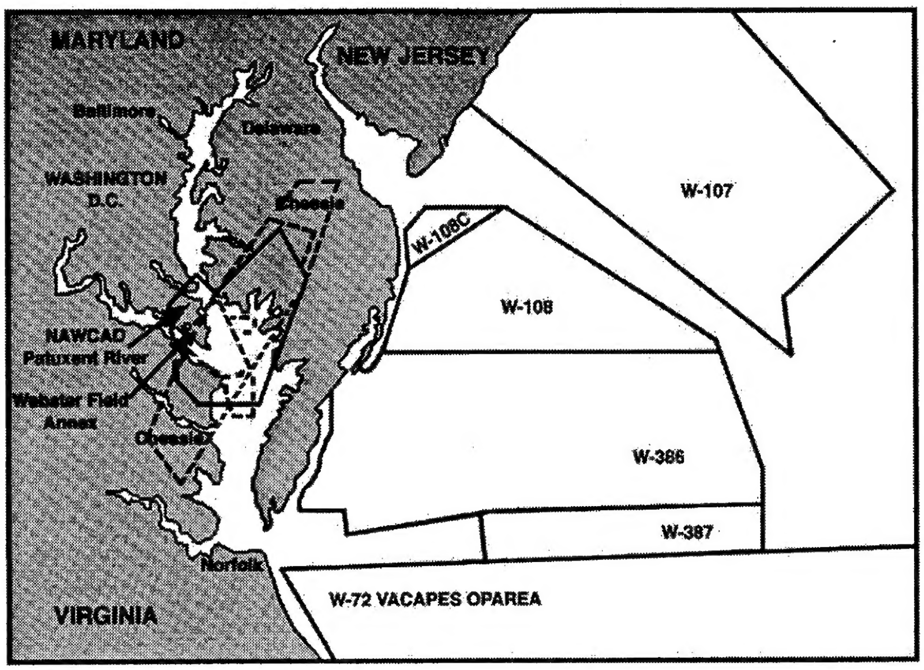
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Figure 5

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- Overview of current programs
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